Full Body Interaction : Toward an integration of Individual Differences

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UNIVERSITÉ PARIS-SUD
ÉCOLE DOCTORALE 427
INFORMATIQUE PARIS SUD
Laboratoire LIMSI-CNRS

Full Body Interaction

Toward an integration of Individual Differences

THÈSE DE DOCTORAT
INFORMATIQUE

par
Tom GIRAUD

Soutenance le 26/03/2015

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ABSTRACT

In human computer interaction, virtual humans are now established as a specific object of research. They build on human to human interaction routines to serve various application goals. Although Virtual Humans (VH) have bodies, current researches suffer from two major limitations which impair the experienced credibility: modeled bodily behaviors lack of social interactivity and do not account for individual differences. Recent developments in human sciences call for a more integrative approach with at its heart the constitutive role of social interaction. Of particular importance is the central and interdisciplinary position of virtual humans in this new research agenda: they are both a way to better investigate the various socially interactive phenomena (VH as experimental tools) and potential solutions for societal challenges (VH as applications).

The main goal of this PhD thesis is to contribute to both computer and human sciences by studying together bodily interaction and individual differences. Central to this study is the long term objective to develop interactive virtual humans at the interface of these domains, with the idea that requirements from both fields would constrain positively future propositions. To limit the scope of the thesis, we focused on body movements (not considering static bodily aspects or other modalities), low level coupling mechanisms and the moderating role of individual differences with the aim to propose proof of concept of virtual human prototypes (rather than complete functional software) embedding full body dyadic interaction models.

Our research methodology can be summarized in four main steps. First, models and hypotheses linking social interaction processes and individual differences emerged from a review of the literature in both computer and human sciences. As the identified relevant individual differences appeared barely theoretically associated, our second step aimed at investigating their interrelatedness in a large scale study. Thirdly, bodily interactions were analyzed in two case studies which present application and experimental interests. In both cases, corpuses were collected with full body interacting dyads and individual differences measured. The final phase was to develop virtual human prototypes inspired by previous analyses and based on the collected data.

The proposed general model of individual differences was shown to be consistent with real word data (collected by self-report questionnaires): dispositions in pro-social orientations, empathy and emotion regulation were closely related. The two case studies partially confirmed our initial hypotheses: various individual differences modulated the bodily interactive processes. These studies enabled the definition of parsimonious virtual human interactive models. The main critical contribution of the two case studies to the proposed model of individual differences is the clear necessity to take into consideration the task context before drawing any hypotheses. Future directions of research are proposed including an integration of individual differences identified in case studies.

RESUME

Les humains virtuels en interaction homme machine sont aujourd'hui établis comme un objet de recherche à part entière. Leurs comportements pensés pour différentes applications sont basés sur les routines d'interaction entre humains. Bien que les humains virtuels aient souvent un corps représenté graphiquement, les recherches actuelles souffrent de deux limitations majeures qui dégradent la crédibilité de l'expérience des utilisateurs : les comportements corporels modélisés manquent d'interactivité sociale et ne prennent pas en compte les différences interindividuelles. Les développements récents en Sciences Humaines promeuvent une approche plus intégrative avec en son cœur le rôle constitutif de l'interaction sociale. La position centrale et interdisciplinaire des humains virtuels dans ce nouvel agenda de recherche est particulièrement importante : ils sont à la fois une manière de mieux étudier les différents phénomènes d'interactions sociales (comme outil expérimental) et une solution potentielle à des défis sociétaux (comme applications).

L'objectif principal de cette thèse est de combiner les apports et valoriser les synergies établies entre les sciences de l'informatique et les sciences humaines, afin d'appréhender le rôle modérateur des différences interindividuelles dans le contrôle et la régulation des interactions corporelles. L'objectif à plus long terme de cette contribution vise à développer des humains virtuels interactifs à l'interface de ces domaines, avec l'idée que les besoins des deux champs de recherches contraindraient de manière positive les propositions futures. Pour limiter le cadre de cette thèse, nous nous sommes concentrés sur les mouvements du corps (les aspects statiques du corps ou les autres modalités ne sont pas considérées), sur les mécanismes de couplages bas niveaux et le rôle modérateur des différences interindividuelles avec comme objectif de proposer des prototypes d'humains virtuels comme preuve de concept (plutôt que des logiciels fonctionnels complets) incluant des modèles d'interaction corporelle dyadique.

Notre méthodologie de recherche peut être résumée en quatre étapes principales. Premièrement, les modèles et hypothèses liant les processus d'interaction sociale aux différences interindividuelles résultent d'une double revue de littérature en sciences de l'informatique et sciences humaines. Ces différences interindividuelles identifiées comme pertinentes apparaissant faiblement associées théoriquement, notre seconde étape consista à étudier leurs associations lors d'une étude à grande échelle. Troisièmement, les interactions corporelles ont été analysées dans deux études de cas qui présentent des intérêts applicatifs et expérimentaux. Dans les deux cas, des corpus multimodaux d'interactions corporelles dyadiques ont été collectés et associés à des mesures de différences interindividuelles. La phase finale fut de développer des prototypes d'humains virtuels inspirés par les analyses précédentes et basés sur les données collectées.

Le modèle général portant sur la prise en compte des différences interindividuelles se révèle en accord avec les données collectées (questionnaires d'auto-évaluation) : les relations entre dispositions d'orientations pro-sociales, d'empathie et de régulation émotionnelle furent confirmées. Les deux études de cas validèrent partiellement les hypothèses initiales : certaines différences interindividuelles modulèrent les processus d'interaction corporelle. Ces études contribuent à la définition de modèles d'humains virtuels interactifs parcimonieux. La principale contribution critique de ces deux études de cas au rôle modérateur des différences interindividuelles dans le modèle proposé est la nécessité de prendre en considération le contexte de la tâche avant de définir les hypothèses. L'intégration de ces différences interindividuelles identifiées dans les études de cas aux modèles informatiques interactifs est incluse dans les directions de recherches futures.

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Un travail scientifique n'a que peu de valeur sans le regard attentif et bienveillant de ses pairs. Je tiens à remercier l'ensemble des membres du jury pour l'intérêt et le temps qu'ils ont accordé à ce travail. Nadia Bianchi Berthouze et Elisabeth André, rapporteuses de ce manuscrit, pour leur travail de relecture et leurs commentaires constructifs. Je remercie également Pierre De Loor et Christian Jacquemin pour avoir accepté d'examiner cette production. C'est un honneur d'avoir pu discuter de ce travail avec vous quatre. Je remercie mes deux directeurs de thèse, Jean Claude Martin et Brice Isableu, et à travers eux les laboratoires qui m'ont accueilli. Le LIMSI, mon laboratoire d'accueil principal, est un laboratoire chaleureux, qui s'apprécie à mesure qu'on le découvre. Le CIAMS, laboratoire d'accueil plus ponctuel, est un lieu accueillant, plein de vie et source d'interactions déterminantes. Jean Claude, merci d'avoir dirigé cette thèse avec le *juste* niveau d'encadrement : des contraintes là où il fallait, une liberté de recherche comme il le fallait. C'est un équilibre délicat à trouver pour l'épanouissement d'un jeune chercheur. Merci aussi de m'avoir permis autant de rencontres interdisciplinaires, en France et ailleurs. Brice, merci pour ce pas de côté vers une approche plus exploratoire, plus interdisciplinaire. Merci pour ton enthousiasme et ton sens de l'abnégation, lorsqu'il a fallu arrêter de creuser par ici pour avancer par-là (notamment pour la DIC). Merci à tous les deux pour votre entente et votre complémentarité, vous faites une bonne paire ! Merci à toutes les personnes avec qui j'ai collaboré au LIMSI et au CIAMS. Au LIMSI, mes pensées vont à cinq personnes qui ont compté dans l'aboutissement de cette thèse : Matthieu Courgeon, Mariette Soury, Virginie Demulier, David Gomez, et Florian Focone. Je remercie également les membres de l'équipe CPU (entre autre!) avec qui j'ai interagi aux cours de cette thèse : Léonor, Mehdi, Caroline, Sylvain, Yacine, Yoren, Atef, Kévin, Céline, Vincent, Nicolas, Gabriel, Gaëtan, David, Brian, Pierre, Weyia. Vous avez formé un environnement de recherche vivifiant. Merci à tous. Au CIAMS, merci à Clint Hansen, David Gibas, Marine Godel et Jiewen Hua pour les échanges et le travail réalisé ensemble, à Jean Jeuvrey et Nicolas Morvan pour leur accompagnement, et plus généralement à l'ensemble des doctorants pour leur accueil. Au cours de cette thèse, j'ai eu la chance de pouvoir m'investir sur divers projets connexes, d'exploration, art-science, m'offrant de grands bols d'air frais intellectuels ainsi que des perspectives de recherches passionnantes. Pour cette nouvelle aventure, je remercie Xavier Maitre et toute l'équipe du SAS. Je remercie sincèrement l'ensemble de mes ami(e)s pour leur présence, leur regard tantôt bienveillant tantôt critique, leur scepticisme comme leur enthousiasme, les engueulades et les retrouvailles. Je tiens à remercier plus particulièrement les anciens collègues, toujours amis, du CAOR (Jean-François, Vincent, Raoul, Sylvain, et un peu au-delà : Judith et Kévin) avec qui j'ai pu m'échapper tant de fois pour de courtes et agréables soirées à refaire la thèse mais aussi à l'oublier. Je terminerais ces remerciements par ma famille, de sang et de cœur, sans laquelle rien n'aurait été, ne serait et ne sera possible. Merci à mes parents, mon frère et ma sœur pour leur bienveillance, leur confiance, leur amour et pour ce sentiment unique de faire partie d'un tout. Merci à Luce d'être toujours à mes côtés, à partager, encaisser, donner, écouter, aimer, avancer. J'espère arriver à te porter comme tu l'as fait avec moi durant cette thèse, et comme probablement tu continueras à le faire pendant un paquet de temps.

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David Gibas (former psychology PhD student): We undertook the large investigation from chapter 3 together. Working on Narcissism, he was interested in locating Narcissism within the various individual differences I was also interested in. More than half of all the tests from chapter 3 were administrated by him and a master student – Marine Godel – in his sports department. The theory, methodology and analyses in chapter 3 emerged through various discussions, debates and data file exchanges.

Mariette Soury (former computer sciences PhD student): She worked on the COMPARSE corpus acquisition (chapter 4) and took care of the voice recording. She was interested in automatically detecting stress in the voice. We shared the manual segmentation of the entire corpus (time stamping beginning and end of all sentences) of the participants.

Jiewen Hua (former psychology PhD student): She took care of administrating the personality and self-report questionnaires during the COMPARSE corpus collect (chapter 4) (and collected the saliva samples!) and computing the overall scores for each dimensions.

David Gomez (current computer sciences Post-Doc): Originally specialized in computer vision, he took care of the automatic extraction of signals from RGB videos (e.g., quantity of motion) for the entire COMPARSE corpus. Additionally, we shared the manual and automatic segmentation procedure of judges' behaviors. Finally, he is currently working on the implementation and design of the virtual judge described at the end of chapter 4. Future evaluation will only be possible thanks to him.

Virginie Demulier (current psychology associate professor): Working on the project INGREDIBLE (chapter 5), she was implicated in the different tentative steps before ending up with the concept of the virtual fitness coach (tasks identification and classification, predefined gestures and choreography propositions, etc.). She participated in the design of the corpus, the experimentations themselves and their subsequent analyses.

Florian Focone (current movement sciences PhD student): He also works on the project INGREDIBLE and as Virginie was equally implicated in the design of the corpus, the experimentations themselves and their subsequent analyses. He undertook the major part of the work related to motion capture issues: post-treatment of the data and movement qualities computations. My work and his are highly complementary making his contributions essential to the results presented in chapter 5.

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This PhD thesis deals with the human body engaged in dyadic interactions. More specifically, the goal is to consider individual differences (e.g., personality traits, self-definition or socio-emotion competence) and affect (e.g., emotions, moods) as individual variables modulating bodily interactions. This introduction describes the current context within the different research areas related to the topic and briefly highlight the current limitations of the state of the art. Research scope, aims and approach are then described.

1. COMPUTER SCIENCES: CONTEXT AND LIMITATIONS

1.1. Human-computer interaction is getting social

Nowadays, computing is no more restricted to office uses. Being totally pervasive, computers and software are present everywhere, from public spaces to private homes, from childhood to elderly, from professional simulations to entertainment and healthcare. This opens a wide variety of areas with new potential applications and users' scenario for Human Computer Interaction (HCI). Considering both user experiences and technological developments, this research object is fundamentally interdisciplinary.

Interactive systems can be located within three primary interaction paradigms: Computer-as-Tool, Computer-as-Partner and Computer-as-Medium (Beaudouin-Lafon 2004). If traditionally HCI is mainly concerned by computers as tools, the Computer-as-Partner paradigm got increasing interest from computer scientists with the development of "*software agents*". "*The user is engaged in a cooperative process in which human and these computer agents both initiate communication and perform tasks*" (Maes 1994). This period is also marked by an increasing consideration of social aspects in HCI. Works from (Reeves and Nass 1994) revealed how humans tend to treat computer systems as real humans and coined this process the "*Media Equation*". The domain of Affective Computing emerged placing emotion phenomena at the heart of intelligent systems (Picard 1997). Computer systems can adapt by recognizing the user emotional state, but also giving emotions to computer systems can help them take decisions.

1.2. Interactive Virtual Humans

One line of research in HCI is the design of anthropomorphic representations of agents. The main advantage of embodying an autonomous agent is to take benefit from human to human interaction routines: "*The qualitative difference is that the human body enables the use of certain communication protocols in face-to-face conversation. The use of gaze, gesture, intonation, and body posture plays an essential role in the proper execution of many conversational behaviors*" (Cassell et al. 2001).

Interactive Virtual Humans (IVH) are systems that both exhibit human-like qualities to enable the transmission of nonverbal signals and recognize relevant users' social cues. To be interactive, the IVH should include three components: a behavior generation module, a behavior recognition module and an interactive model guiding the correspondence between the two (Kasap and Magnenat-Thalmann 2008). Depending on which aspects the research focus on, the system is endowed with different skills and the definition might vary. *Embodied Conversational Agents* (ECA) concentrate research efforts on conversational skills (Justine Cassell et al. 1994) such as turn taking, backchannel (Ruttkay and Pelachaud 2004) or rapport in dyadic interaction (Zhao, Papangelis, and Cassell 2014). *Anthropomorphic characters* or *life-like characters* often concern the research area where naturalness of the representation and behaviors are central (André et al. 2000). *Reactive Virtual Humans* (RCH) emphasize the recognition-reaction loop in an autonomic manner without involving higher cognitive processes at the contrary of *Intelligent Virtual Humans* (Ruttkay et al. 2006). Finally, as robot are also endowed with social skills and anthropomorphic configurations (Fong, Nourbakhsh, and Dautenhahn 2003) (Breazeal 2003), some authors can

group them with virtual humans under the label *artificial social entities or artificial social agents* (Vogeley and Bente 2010).

Since the 90s, several generations of interactive virtual humans have been proposed pushing the limits of naturalness and interactivity (I. Poggi et al. 2005) (Courgeon and Clavel 2013). An interesting duality of virtual humans is that they can both be designed for a specific application – research issues will deal with believability of the agent – and for experimentally testing theoretical models of humans – research issues will deal with the verification of hypotheses from human sciences – (Burghouts et al. 2003). Recent efforts are made to integrate different works from the research community such as with the SAIBA framework or the Virtual Human Toolkit (VHT) (Hartholt et al. 2013), and standardizes representation languages such as the Behavior Markup Language (BML, (Vilhjálmsson et al. 2007)) or the Perceptual Markup Language (PML, (S. Scherer et al. 2012) which suggest to separate modules dedicated to the mind versus the body of the virtual agent (Isabella Poggi 2007).

Figure 1: a) PPP (André, Müller, and Rist 1996) b) GRETA (Poggi et al. 2005) c) MARC (Courgeon and Clavel 2013) d) VHT (Hartholt et al. 2013)

1.3. Applications for full body interaction

Many applications exist where virtual humans with full body interactive skills are relevant. Presenters or guides are classical examples: the virtual human delivers the necessary information via its voice and uses its body to express emotions, attitudes, and react to visitors' behaviors (Swartout et al. 2010). Video games are already populated with a variety of intelligent virtual humans that the gamer can meet and interact with. In education programs, many disciplines benefit from simulating a full body interaction in order to train student facing realistic situations (Johnsen et al. 2007). In the health care domain, whole body engaging virtual humans is a new tool for therapist to guide patient to self-disclosure behaviors (DeVault et al. 2014).

In response to current societal challenges, efforts seem to be concentrated on applications with high societal potentials. With the lack of a daily physical activity being one of the main health risk factor in our modern societies, sport virtual trainers (i.e. Tai-chi, biking, fitness) can provide personalized physical training with performance feedbacks and motivational supports (Lowe and ÓLaighin 2012). Providing body movement guidance and reactivity is a key point to engagement in such a scenario (Ruttkay et al. 2006).

Another contemporary problem is the economic crisis which leaves millions of unemployed people. When looking for a job, individuals go through several job interviews, an emotionally engaging moment which can be traumatizing in case of failure and puts high constraints on proper nonverbal communication. Helping people to manage their emotions and interact smoothly with recruiters is a key challenge where virtual humans can be used as a real life

simulation (Hoque et al. 2013) (Baur et al. 2013) as shown by several cooperative national and international projects (TARDIS, MACH, COMPARSE).

1.4. Raising interests for bodies

Embodying computational systems means giving them a body. However, the consideration of the whole body as a communicative channel in HCI, Affective Computing and Virtual Humans is rather recent (England 2011). Most of the research focused on the face and the voice concentrating communicative functions in the head. Hands and arms were studied within a co-verbal context (Kopp and Wachsmuth 2004)(Michael Kipp et al. 2007) and deictic studied for functional applications (Lester et al. 1999). Most recent works give more importance to the body with increasing interest in whole body expressive behaviors such as emotion expressions (A. Kleinsmith and Bianchi-Berthouze 2013). This current raising interest for full body interaction can be considered as the results of two concordant developments: the development in human sciences of theories about embodied social cognition and the emergence of technologies enabling full body interaction.

In human sciences, various authors re-emphasize the central role of the body in social interactive situations (Niedenthal et al. 2005) going beyond the mere use of posture shift for signaling topic changes (Justine Cassell et al. 2001). Body postures are shown to convey various social information such as emotions and attitudes (Bull 1987), motion kinematics can reveal person attributes such as gender and age (Johansson 1973)(Runeson and Frykholm 1983) and mimicking confederates body postures and movement facilitate the smoothness of interaction (Chartrand and Bargh 1999). In addition, technological advances enable the analysis, modeling and implementation of full body interactions in an affordable way. With the development of motion example based animation techniques for video games and movies, several technologies for full body motion capture have been developed, years bringing better precision while lowering costs. The possibility to constitute full body motion corpora such as PACO (Ma, Paterson, and Pollick 2006) or AffecteMe (Andrea Kleinsmith, De Silva, and Bianchi-Berthouze 2006) is a significant progress for the scientific community. Yet, although some recent efforts are made to collect corpora with several people interacting (CID, (Ferré, Bertrand, and Blache 2007)), most corpora are limited to a single person's movements (Gross and Shi 2001). Low cost sensors accessible to everyone are also flourishing, driven by the entertainment industry. Depth cameras (e.g. Kinect One), force plates (e.g. Wii Balance) or accelerometers (e.g. smartphones) are interesting sensors to capture movements from moving users. At the software level, these systems are often coming with a relatively open Software Development Kit, enabling developers to use their sensors in non-proprietary systems. In addition to sense user motions, today's technologies (e.g. Occulus Rifts) enable to display full body animated virtual humans in scale one to simulate human bodily behaviors.

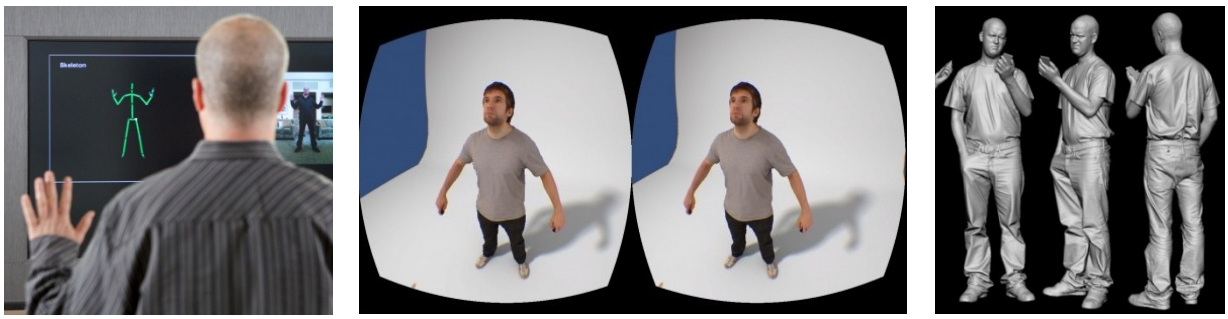


Figure 2: a) Kinect One b) Occulus Rift view of a virtual human c) Infinite realities scan

Finally, latest computer graphics hardware and software enable to approach body photorealism with new 3D scanning methods while keeping the possibility to animate these models in real-time. Full body 3D representations

are on sale and technologies for fast homemade virtual humans are available to everyone (Feng et al. 2014). The combination of these three technological aspects, sensing, displaying and modeling, contribute to the growing availability of full body interaction systems.

1.5. Emotion and Personality: personalized interactions

Making credible interactive behaviors for virtual agent has quickly been associated with the integration of variability in states such as emotions and individual features such as personality (Paiva 2000). These intra and inter individual variables are key components for giving sense to social behaviors within the interaction (Ball and Breese 2000). Personality and emotions can be used as constrains or guides in the decision process when generating agent's behaviors. The concordant consideration of both emotion and personality is not so often done in the virtual human community although they are tightly linked (André et al. 2000). A helpful analogy is to consider that personality is to emotion as climate is to weather (Revelle and Scherer 2009). That is, what one expects is personality, what one observes at any particular moment is emotion. The analysis and modeling of full body emotions is gaining more and more interest from the research community (A. Kleinsmith and Bianchi-Berthouze 2013) (Karg et al. 2013). One limitation of the current literature is the lack of dyadic interactive scenario: most of the work is done on single individuals. Some works consider the empathic reaction process of virtual humans to provide adapted feedbacks to users (Boukricha et al. 2013) or the impact of emotion generation on the interaction outcomes (Qu et al. 2014). While emotions are in essence directly related to body actions (Frijda 1986), the embodied nature of personality is more indirect and traits are considered as a characterization of behavior consistencies across time and situations. As such, it is often associated to bodily behaviors through the concept of expressivity (Doce et al. 2010). Personality traits can also be related to bodily expressions via their influence on felt emotions. However, personality traits are not often considered as determinant of bodily behaviors, works being mostly done on co-verbal elements within a conversation such as gestures and backchannels (McRorie et al. 2009) or formational parameters of hand gestures (M. Kipp and Martin 2009). One explanation might be that the vast majority of personality computing focus on the Five Factor model of personality: 76 papers out of 81 reviewed in (Vinciarelli and Mohammadi 2013) used this personality definition which does not emphasize full body related behaviors.

1.6. Synthesis and motivations

Looking at this short synthesis, it appears that most of the conditions are coming into place for a fruitful investigation of personalized full body interactions in virtual humans: the technology enables to sense and synthesize full body motion, applications with critical societal benefits are identified and the computing research community has accumulated knowledge about related issues such as personalized backchannels or recognition and synthesis of full body emotion expressions. The fields of IVA and Affective Computing are getting well-structured with various areas of specializations emerging. This atomization of research questions enables to go deeper in many topics with more rigorous research methodologies. However, one limitation of current developments resides exactly in this atomization: to understand how bodies move together in social situation, it appears necessary to jointly consider the interactive situation, the involved bodies and related individual differences modulating them (Figure 3).

The focus of computer scientist on the Five Factor model as the main framework of individual differences seems to limit the possibility for sound hypotheses about interactive situations. **The first motivation for this PhD thesis was therefore to enlarge our view on theoretical models of individual differences (e.g., personality traits) potentially related to interactive bodily behaviors.**

A second aspect of the current state of affair in computer sciences is the lack of low level mutual adjustment models for bodily interactions. Within the thin literature involving full body virtual humans reacting to users bodily

behaviors, body reactions are either generated based on heuristics (Gratch et al. 2006) or theory of mind model to infer mental state and generate an appropriate response (DeVault et al. 2014). A recent trend is to ground interactive mechanisms on collected data such as for backchannel (Morency, Kok, and Gratch 2010) or more recently continuous full body movement (Yang, Metallinou, and Narayanan 2014). **The second motivation for this PhD thesis was to contribute to this last line of research by building data-driven interactive full body behaviors as well as to provide a more in depth theoretical analysis of the underlying processes.**

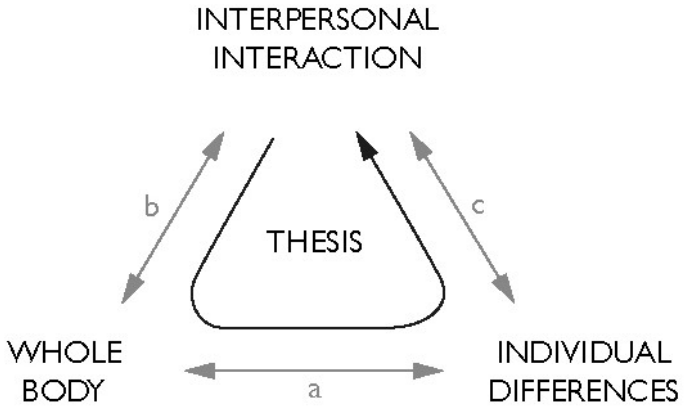


Figure 3: Example of studies considering pairwise research questions a) (Kleinsmith, and Bianchi-Berthouze 2006) b) (Billon, Nédélec, and Tisseau 2010) c) (Bevacqua et al. 2012)

In order to get more insight of potentially relevant individual differences and interpersonal bodily processes, a close look at the Human Sciences literature is required.

2. HUMAN SCIENCES: CONTEXT AND LIMITATIONS

The development of social interactive models in Computer Science is tightly linked to advances in Human Sciences (HS). As in HCI, the study of interpersonal bodily interaction in HS is inherently an interdisciplinary object of research. Social psychology and human ethology bring complementary frameworks and tools to capture dyadic interaction mechanisms, the complex system of the human body is analyzed by biomechanics and motor control and the investigation of stable differences in ways of behaving is the domain of personality psychology. Traditionally well separated, recent advances in the understanding of social cognition are bringing about a radical shift in their articulation.

2.1. Embodied cognition: the corporeal turn

Perhaps the most determinant factor of research orientations and hypotheses in Human Sciences is the way scientist conceptualize the human mind. The Cognitive Revolution marked a major and durable shift sixty years ago by reconsidering cognitive processes through the computer metaphor. Within this paradigm, knowledge resides in a semantic memory system separate from perception and action, with the mind as an abstract information processor (Wilson 2002). This perspective with the software (the mind) independent from the hardware (the body) explain in part why bodily aspects were peripherally studied in cognition and social interactions (Niedenthal et al. 2005).

Another stance is currently gaining visibility which emphasizes sensory and motor functions: "*growing commitment to the idea that the mind must be understood in the context of its relationship to a physical body that interacts with the world*" (Wilson 2002). This perspective is rooted in some early influential authors such as William James for its theory of emotions (James 1884), James Gibson for its ecological theory of visual perception (Gibson 1950) or Jean Piaget for its constructivist theory of mind (Piaget and Cook 1954). Today this stance of "*Grounded Cognition*" undertakes many different forms still not unified (Barsalou 2008). One line of research focus on situated action where cognition evolved to support action in specific situations. Another direction studies reenactment theories of perceptual and motor states acquired during experiences with the environment. Lastly and most relevant for this thesis, accumulating research demonstrate the direct impact of bodily states and acts on cognitive processes. This circular causality is the starting point for all works done under the "*embodied cognition*" paradigm (Niedenthal et al. 2005). Interestingly, the close links between mind and body provided prolific hypothesis for the study of social perception, coordination and empathy (Niedenthal et al. 2005). Following this shift in the conceptualization of cognition, the role of the body is increasingly taken into account for various fundamental human processes such as emotions.

Although considered from the very first theories (Darwin 1872) (James 1884), the interest for the role of the full body in affective communication is recent (de Gelder 2009). Emotions are known to be expressed and recognized through body postures and movements (A. Kleinsmith and Bianchi-Berthouze 2013). Feeling of emotions requires the participation of somatosensory cortices (Damasio et al. 2000), modulates muscle contraction (Coombes, Cauraugh, and Janelle 2006) (Huis In 't Veld, Van Boxtel, and de Gelder 2014) and are associated with schematic representations of upward and downward motion (Casasanto and Dijkstra 2010). The main theoretical framework used to predict motion-emotion congruencies is action tendencies (Frijda 1986). Mainly described as discrete phenomena, emotions can alternatively be studied with dimensional approaches (K. R. Scherer 2010). Valence (intrinsic pleasantness of the emotion-eliciting object), arousal (degree of physiological activation) and potency (individual's sense of control over the emotion-eliciting event) are the principal axes used. The association between emotion and movement has been shown to be inherently bidirectional (Laird and Lacasse 2014)(Fuchs and Koch 2014). This circular causality has been traditionally studied within the framework of approach avoidance theory (and corresponding behaviors).

Interestingly this corporeal turn seems to not touch directly personality psychology. Although an increasing number of papers about embodied phenomena acknowledges the potential influence of individual dispositions (e.g., (Chartrand and Bargh 1999)), no reconceptualization of individual differences more directly related to the body is occurring.

2.2. Interpersonal communication: the interactive turn

The study of social phenomena at the individual level was traditionally the domain of social psychology. It encompasses a variety of topics such as social determination of individual behaviors, collective processes and group dynamics, and interpersonal relationship (Fischer 1987). However, the focus on dyadic interactive situations has mainly been the object of the sub-domain coined communication sciences emerging in the 50s. The definition of what is communication is of primary importance as it defines the object of research in social interactions. Various conceptualization have been proposed which can be classified with three inclusion criteria: the meaning of the behavior (shared or not), the spontaneity of the behavior (intentional or not), and the consequences of the behavior (influence on others' behaviors or not). Following (Burgoon et al 1996), human communication has long been considered as a process of exchanging meaningful signals. These independent units have shared meanings as in verbal communication and form utterances: this position is very close to a linguistic view of communication. Works on body language and discrete gestures tend to consider body behaviors in this perspective (Kendon 2004). As a consequence, the continuous and implicit dimension of behaviors has long been neglected in the social psychology

literature (Wallbott 1985). Another school of communication ("*Palo Alto school*") follows the definition given by (Wilson 1979) which emphasis the mutual influence of behaviors rather than their inferred meanings or the intentions behind it: the interaction process is at the heart of communication. Within this theoretical framework, communication has two levels: the information level of the conversation and the relational level. Where the information level is discrete, explicit and certain (the domain of linguistics), the relational level is analogous, implicit and ambiguous. Considered as such, communication emphasizes the importance of automatic and pre-reflexive behaviors which are often dynamics in nature as opposed to semantic aspect of the interaction (Bargh and Chartrand 1999) (Vogeley and Bente 2010). The ambiguous essence of this level gives the place to mutual adjustment where "*patterns of behaviors are negotiated subtly and move typically toward some degree of stability*" (Patterson 2006).

This approach to interpersonal communication is currently gaining interests thanks to the development of the study of interpersonal bodily coordination. Interpersonal nonverbal coordination as a research topic emerged in the 70s when videos enable the analysis a dyadic interaction in ecological context (Condon and Ogston, 1966). This general term encompass all forms of bodily attunement: "*interpersonal coordination is the degree to which the behaviors in an interaction are nonrandom, patterned, or synchronized in both timing and form*" (Bernieri and Rosenthal 1991). Since the 90s, two distinct lines of research are identified: behavior matching (or mimicry) which occurs when two people show similar body configurations (Chartrand and Bargh 1999) and interactional synchrony which focus on how behaviors are coupled in time rather than in form (Marsh, Richardson, and Schmidt 2009). Interestingly, these two interpersonal processes are grounded in different theoretical paradigms emerging from different research disciplines (social psychology for the former, movement sciences for the later). In both cases, the coupling of bodies have been associated with positive outcomes such as rapport, liking and affiliation leading researchers to consider these processes as a social glue (Chartrand and Lakin 2013).

More than just a new emerging topic in Human Sciences, the efforts made to uncover the essence of social interactions might lead to a more radical shift in the conceptualization of social cognition. Building on the fact that "*empirical results already imply that social cognition is not reducible to the workings of individual cognitive mechanisms*", (De Jaegher, Di Paolo, and Gallagher 2010) propose to re-consider social interactions as constitutive of social cognition. In opposition to a methodological individualism (Lenay and Stewart 2012) where individuals are tested alone facing "*social stimulus*", tradition inherited from a cognitivist approach reducing research issues of social phenomena as "*preoccupation with social information processing*" (Ickes et al. 1988), they argued that if one want to grasp the essence of social cognition the methodological paradigm should shift toward two bodies experiments (De Jaegher, Di Paolo, and Gallagher 2010).

2.3. Disposed to be social: individual differences

While most branches of psychology are concerned with how people behave in a universal way, the variations among behaviors between humans are pervasive. "*The psychology of individual differences seeks to understand how we should best describe the ways in which people vary, and to understand how and why such variations in behaviors came out*" (Cooper 2002). Traditionally, personality traits have been conceived as value-free (no particular score on a trait is better than another) "*set of organized, stable and individualized behaviors*" (Mischel, Shoda, and Smith 2003) in opposition to ability traits which represent the level of performance of an individual for a particular adaptive quality (Cooper 2002). Both literatures leaded to the design and validation of general traits encompassing a wide variety of sub-component. In the personality literature, this integrative approach provides us with the Five Factor model of personality (Costa and McCrae 1992). In the ability literature, the concept of general intelligence with a hierarchical structure emerged (Cooper 1999). Interestingly, the same integrative process occurred in the development of the concept of emotional intelligence (Salovey and Mayer 1989).

This approach to individual differences is very general and of little help for researchers interested in specific situations. Current researchers investigating social interaction processes most of the time move on more specific traits explicitly related to affiliative motives. For example, perspective taking (a sub-component of dispositional empathy (Davis 1983)) and self-construal interdependence (a dimension of self-construal which refer to the way people see themselves in relation with others (Singelis 1994)) have been evidenced to facilitate spontaneous bodily mimicry (Chartrand and Lakin 2013). Grounded on the idea that individuals are social in nature (Baumeister and Leary 1995) but conserving an essential level of autonomy (Chirkov et al. 2003), a new trend investigates dispositions which characterize the way individuals relate to each other's. Some authors have even began an integration work of these dispositions (Luyten and Blatt 2013). This orientation appears to be a promising route bringing together individual differences and interpersonal processes.

2.4. Synthesis and motivations

A fertile ground already exists in the study of social interaction. A shift in the understanding of social cognition is emerging throw the joint consideration of bodies and interactions as constitutive of our human experience. Researchers are acknowledging the need to encourage two bodies experimental setup to enable the emergence of engaging interactions (De Jaegher, Di Paolo, and Gallagher 2010). The effort is still at its beginning and very few studies investigate naturalistic dyadic interaction (Latif et al. 2014). Two factors could explain this still limited contribution. Firstly, the study of dyadic interaction in naturalistic setups requires automatic computational analysis which might refrain some researchers from Human Sciences (Paxton and Dale 2013). Secondly, naturalistic situations are hardly controlled to isolate very narrow social phenomena. One line of research is the use of mediated interaction which put individuals in a truly interactive situation but with minimalist action possibilities (Lenay and Stewart 2012). This has been the general approach of dynamical approaches to interpersonal coordination (Schmidt and Richardson 2008). It enables to investigate the essence of the social interaction, but appears to be difficult to transpose to real life situations. A last option involving the HCI community is the use of virtual humans (De Jaegher, Di Paolo, and Gallagher 2010) which can enable the design of truly interactive experimental paradigm (Wilms et al. 2010). When based on real-life data, these virtual humans can re-enact interactive situations in a controlled manner, opening a route which operate a trade-off between naturalist situations and minimalist interactions. **Thus, our third motivation for this PhD thesis was to orient our data driven modeling of virtual humans to open the possibility for these applications to be used as experimental tools.**

Regarding individual differences, it appeared that mainstream concepts of individual differences are rather too general to draw sound hypotheses in the specific case of nonverbal social interactions. Instead, researchers seem to favor dispositions describing the way individuals relate to each other's. **Complementing our first motivation, our fourth motivations for this PhD thesis was to explore the various theoretical models of individual differences apprehending this question in order to select the most relevant ones.**

3. RESEARCH AIMS AND THESIS SCOPE

As it has been highlighted in this introduction, human bodily interactions are emerging as an interdisciplinary topic central for the understanding of social cognition. The general aim of this PhD thesis is the analysis and modeling of dyadic bodily interactions taking into account individual differences. This has been done in the perspective to contribute to the development of both:

- identified IVA applications by the improvement of the feeling of social presence
- IVA based experimental tools for the further understanding of bodily interactions

Such a stand encompassing different research objects and approaches induce to initially enlarge the scope compared to mono-disciplinary works. The different research objects should be reviewed from the different perspectives and the analyses should contribute to both fields.

Also, in order to make the scope fit the PhD thesis format, several focus have to be defined:

- Mono-modal analyses: the body in movement channel alone is considered without considering other channels such as voice, face and static aspects of body (posture, gestures) even if they are present in the task
- Low level coupling mechanisms: higher level adaptation such as interpersonal attitudes (e.g., dominance) expressed through postures are not considered
- Virtual Human prototypes: the objective is to propose proof of concepts and evaluations are left for future works

4. APPROACH AND COLLABORATIVE CONTEXT

In this thesis, we have taken an approach in four main steps:

1/ Review in the perspective of both Computer Sciences and Human Sciences of relevant concepts:

- Full body social interaction processes and their methodological paradigms
- Individual differences related to full body social interactions and their influences

2/ Evaluation of the associations between the selected individual differences on a large panel of individuals to validate our hypothesized model related to bodily interactions

3/ Collect and analysis of two case studies with dyadic bodily interactions and measured individual differences

- Identify and measure bodily variables relevant for the case study
- Study the effect of individual differences on individual behaviors
- Study the interaction and the influence of individual differences

4/ Propose one model of IVA for each of the two case studies inspired by the results from the previous analysis

- Design a scenario with relevant non-verbal behaviors collected via motion capture
- Define a data-driven interactive model and propose a first evaluation of a prediction algorithm of bodily behaviors for the virtual humans

The context of this PhD thesis is highly collaborative as two research projects funded by the French Research Agency (ANR) with related aspects run parallel to it. Conveniently, the two case studies were conducted within the context of these collaborative projects: COMPARSE and INGREDIBLE.

4.1. COMPARSE project

COMPARSE (Cognition, Motivation and Personality for the Adaptation and emotional Regulation by Empathic virtual Simulation) is a project funded by the French Research Agency (ANR). The general goal of the project is to study the adaptation and regulation processes in affective context and identify factors from cognition, motivation and personality which enable humans to modulate their performance. Four laboratories participate in this project: the CIAMS from University Paris South, the LIMSI-CNRS, the ECIPSY from the University Versailles-Saint-Quentin and the CTI from the University of Orleans.

Within this project, several scenarii were designed to vary situations and address different research questions. The first case study of this thesis, the job interview, is one of these scenarii which implicates four different teams. The collected corpora is multimodal including video of full body standing participants and force platform data enabling analyses of subtle balance behaviors. Our specific work reported here concerns the bodily expressions and interaction between the participants and the judges recorded via video and force plate.

4.2. INGREDIBLE project

INGREDIBLE (Credible Gestural Interaction) is a project funded by the French Research Agency (ANR). The general goal of the project is to develop an autonomous virtual human endowed with dynamic and affective full body coupling skills in real time. More specifically the interaction task had to be an explicit synchronization task where a participant should follow the other. One part of the project was on an artistic game inspired by theatrical techniques. Three laboratories participate in this project: the LIMSI-CNRS, the LABSTICC/ENIB, the IRISA/UBS and one company: Virtualys.

In this thesis, we designed a fitness coach scenario in accordance with project partners. The collected corpus used in this thesis is based on full body motion capture data.

4.3. Two case studies, two complementary scenarii

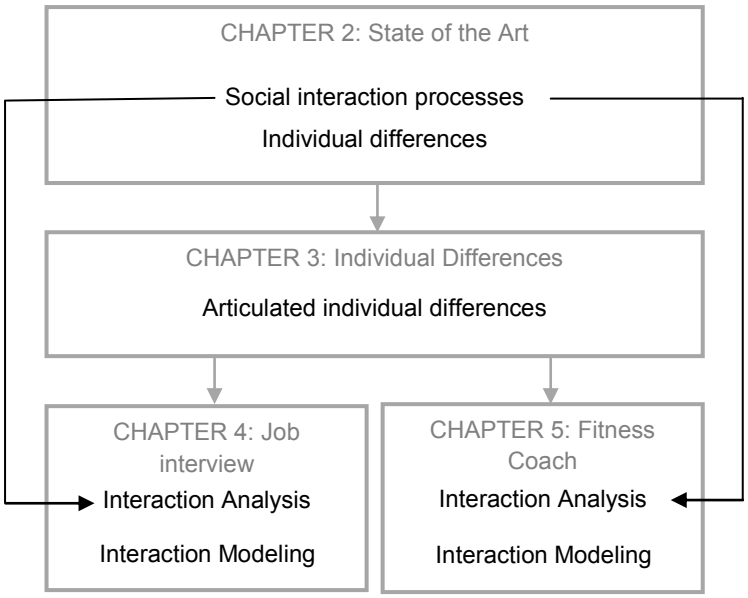
These two projects were the occasion for fruitful encounters (acknowledged in the co-workers section) and provided the opportunity to design protocols and collect data in two different scenarii. The main advantage of working on these two scenarii is the possibility to explore our hypotheses in two complementary case studies.

	Job Interview (COMPARSE project)	Fitness Coach (INGREDIBLE project)
Context	Economic crisis	Health
Attitude	Not affiliative	Affiliative
Associated Affect	Negative, stress	Positive, rappo
Sensors	Forceplate, video	Motion capture
Body variables	Dynamic balance	Movement kinematics

Table 1: Comparison of the two scenarii

5. THESIS OUTLINE

The following of the PhD thesis is structured as follow. Chapter 2 presents the review of the state of art in both Computer Sciences and Human Sciences about social interaction processes and individual differences. Chapter 3 is an investigation of the associations between the individual differences selected from the state of the art. In Chapter 4 and Chapter 5, the two case studies are presented. In both, we focus on social interaction processes identified in Chapter 2 and we consider the influence of individual differences taking into account the articulation found in Chapter 3. Finally, Chapter 6 presents a general conclusion and the potential perspectives of this PhD thesis.



CHAPTER 2
State of the Art

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As stated in the introduction, our interdisciplinary approach in the study of personalized bodily interaction requires a review in the perspective of both Computer Sciences and Human Sciences of relevant concepts:

- Individual differences related to social interactions and their influences
- Social interaction processes and the methodological paradigms for their study

As we will see in this chapter, under the label "*social interaction processes*", we include non-affective low level mechanisms such as synchrony and mimicry but also affect related mechanisms such as empathy.

We first provide a review of the current state of the art in Computer Sciences as it constitutes the point of departure of this PhD thesis. From the identified limitations, we move on a review of the state of the art in Human Sciences. We finally draw a general synthesis and a related interpretative framework.

1. COMPUTER SCIENCES

1.1. Individual differences in computer sciences

Individual differences as dispositions in Computer Sciences are almost synonymous to the use of one specific personality theory: the Five Factor model (A. Vinciarelli and Mohammadi 2014). In their review, (A. Vinciarelli and Mohammadi 2014) proposed to classify the state of the art in three categories: the automatic recognition of personality (the actual self-reported personality), the automatic perception of personality (the judged personality by others) and automatic personality synthesis. As their review include all possible cues to be related with personality, a huge part of the review is focused on personality conveyed through text, speech and social media. Keeping only reported studies on nonverbal behaviors, only few studies remain, especially for the automatic recognition of personality and the automatic perception of personality. Thus, we first review these aspects and then focus in more details on works related to virtual humans, an area more prolific about the association between personality and nonverbal behaviors.

1.1.1. Automatic recognition and perception of personality

The automatic recognition of personality from nonverbal features is recent, past research focusing mainly on text and speech features (Pianesi et al. 2008). Two recent works attempted to predict personality of several persons in a group meeting from nonverbal features, attention patterns and proxemics cues. In (Subramanian et al. 2013), authors build on the assumption that extraverted people attract attention and dominant people pay attention to people while talking but less while listening. They based their prediction model on head pose and proxemics. Similarly and using prosodic features and body activity, (Aran and Gatica-Perez 2013) predicted personality traits as binary outcome (high versus low level on a specific trait) with extraversion being the best predicted trait (75%).

The same evolution exists in the automatic perception of personality from nonverbal features: "*Despite an increasing interest in understanding human perception in social media through the automatic analysis of users' personality, existing attempts have explored user profiles and text blog data only*" (Biel and Gatica-Perez 2013). We found only two studies investigating this issue, both attempting to infer personality impression from large sample of video logs from YouTube (Biel and Gatica-Perez 2013) or from movies (Srivastava et al. 2012). In (Srivastava et al. 2012), 10 items of the Big Five are estimated and nonverbal cues are mainly general image activity providing insight on the role of the body in the inference. (Biel and Gatica-Perez 2013) use a dataset of 442 YouTube vlogs and 2210 annotations

collected via Amazon's Mechanical Turk. They used attentional features as well as one nonverbal feature: movement activity. The best model was a multimodal combination of audio and visual (motion activity).

Together, these works open a new interesting way to investigate the association between personality and nonverbal behaviors. However, they suffer from very gross estimation of bodily behaviors (basically only motion activity) and/or limited interactions. Researchers in the field of Virtual Human went in more details and earlier in the study of personality.

1.1.2. Virtual human nonverbal behavior synthesis of personality

Early works

The pioneer works from (Reeves and Nass 1994) about attributions of social characteristics to computers already gave a central role to personality. In (Nass et al. 1995), authors show how it is possible to create computer personalities with few cues, and how users respond in a coherent manner to this personality (i.e., users prefer to work with computers that match their own personalities (dominant versus submissive) confirming the "*similarity-attraction hypothesis*"). With the development of anthropomorphic agents as metaphors for highly personalized human-machine communication, personality appeared to be a key component to increase believability in the communication process and evoke social responses from the users (Callejas, Griol, and López-Cózar 2014).

Early on, personality has been proposed as a structuring concept to drive social behaviors of believable agents and provide organization and coherence in thoughts, desires and emotions (Rizzo et al. 1997). As personality models such as the Big Five do not provide a framework to determine directly agent behaviors (they are descriptive in essence), several works considered personality as a modulation variable in existing behavioral or affective frameworks (e.g., the OCC model (Clore and Ortony 1988)) to color the interaction. The OCC model (Clore and Ortony 1988) is a framework providing if-then rules to guide how a lifelike agent should affectively react in an environment based on the events, agents, or objects. In (André et al. 2000), an architecture based on the OCC model is proposed where extraversion, agreeableness and neuroticism from the Big Five are included in three different applications ("*Puppet*", "*Inhabited market place*" and "*Presence*"). Ball and colleagues developed a personal assistant endowed with emotion expressions and personality (circumplex model with friendliness and dominance) acting "*as a proxy which influence the particular choice among available behaviors*" (Ball and Breese 2000a),(Ball and Breese 2000b). Such approaches combining emotion as a dynamic component and personality as a static aspect giving goals and attitudes have been proposed by several authors (Egges, Kshirsagar, and Magnenat-Thalmann 2004), (Gebhard 2005), (Liu 2008). (Su, Pham, and Wardhani 2007) proposed a gross integration of emotion, personality and nonverbal behaviors (Table 2).

Emotion	Positive Emotions	Negative Emotions	Kinesphere Zone
Personality	E-H, A-H, N-L	E-L, A-L, N-H	
Head	Face up	Chin down	Vertical
Upper Limbs	Elbows open or Armpits exposed	Arms crossed	Horizontal
	Hands placed Behind the head	Hands clenched In lower position	Vertical
Trunk	Leans backward	Leans forward	Sagittal
	Back straight	Back lowered	Vertical
Lower Limbs	Jump or trot	Draggy or saggy	Vertical

Table 2: associations between personality, emotions and nonverbal behaviors in (Su, Pham, and Wardhani 2007). E – extraversion, A - agreeableness, N – neuroticism, H – high and L – low.

(Doce et al. 2010) went further by associating in a single model the Big Five traits, the OCC model of emotions, goal planning, coping behaviors, and body expressions solely based on the similarities of the descriptions of the different phenomena. One limitation of this line of research is the tendency to overgeneralize stereotyped behavioral patterns.

Common to all these studies is the observation that little empirical evidences linking nonverbal behaviors and personality are available to guide the modeling of personalized conversational agents. As a result, most of them base their models on heuristic rules. For example, (Su, Pham, and Wardhani 2007) noted that extroverted person "*usually stands at ease in an open posture and smiles*". An opposed approach has been followed by (García-Rojas, Gutiérrez, and Thalmann 2008): to model reactive behaviors to unexpected event according to personality profiles, they conducted an experiment where participants had to catch an unexpected ball. Based on these data and participants' personalities, they modeled a decision tree of reactive behaviors influenced by the Big Five traits (Figure 4). Even if the small population (20 participants) prevents from generalizing these results, this first empirical approach provide an interesting alternative to heuristic one going beyond descriptive models.

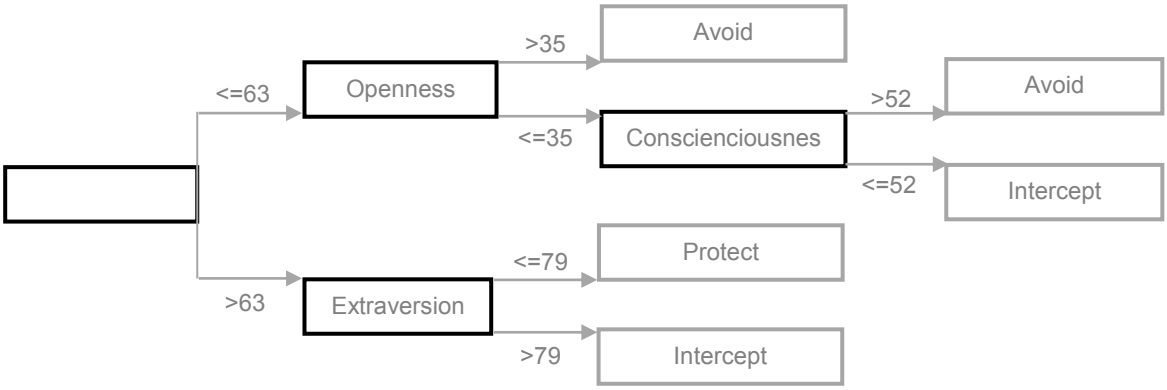


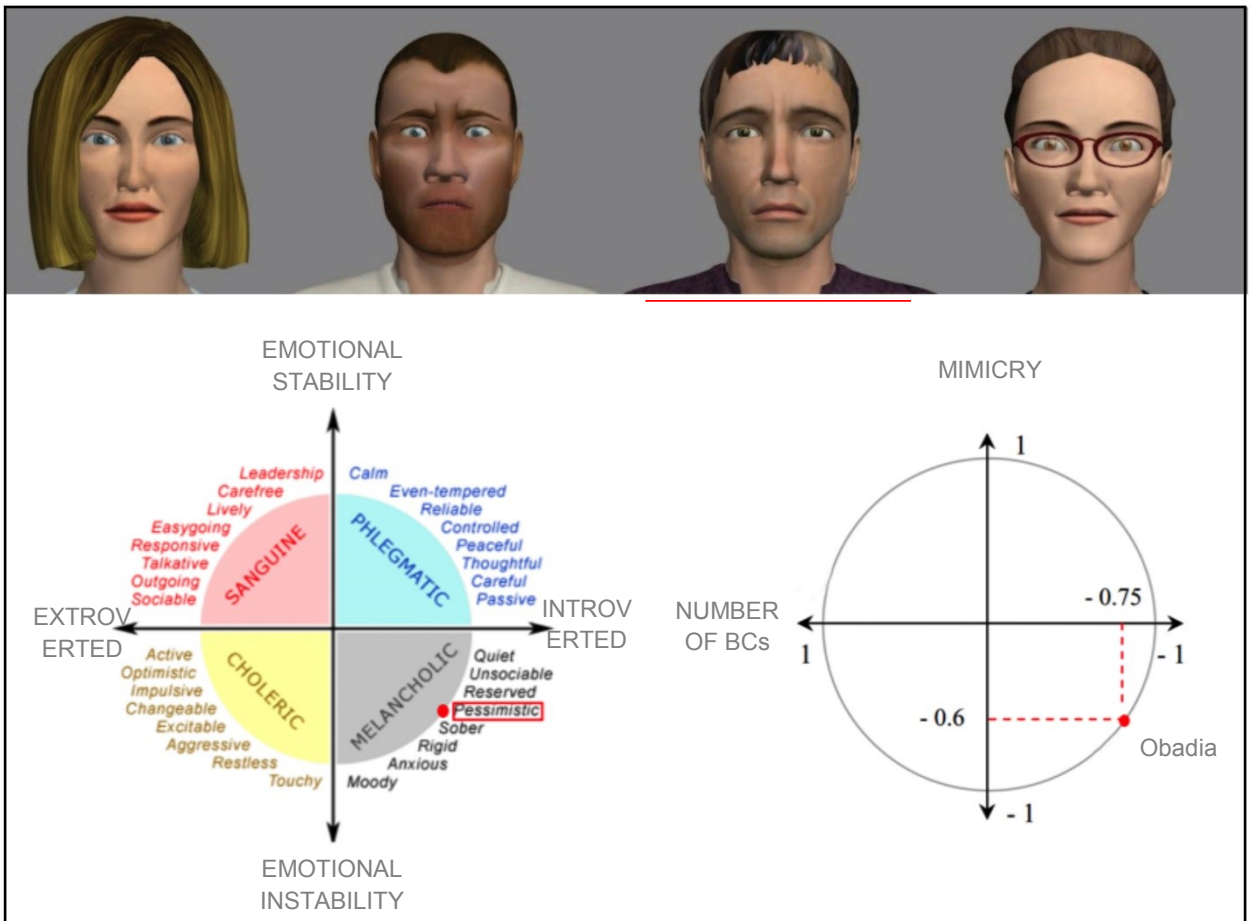
Figure 4: decision tree of reactive behaviors in (García-Rojas, Gutiérrez, and Thalmann 2008)

Such data-driven approaches are emerging as a more viable solution than heuristic solutions given the lack of sound theoretical models for the association of personality traits and nonverbal behaviors (McRorie et al. 2012). However, the difficulty of collecting relevant data limits its development and both approaches are still in use today.

Recent developments on IVA personality synthesis

Some authors focus solely on the expressivity of virtual characters. For example, Neff and colleagues concentrated on nonverbal bodily behaviors and Big Five traits and proposed several associations, between extraversion, gesture rate and movement expansiveness (Neff et al. 2010), and neuroticism and self-adaptors (Neff et al. 2011). The SEMAINE project investigates listener behaviors (Schroder et al. 2012) in an inherently interactive task. However, only the face is explored. The involved teams proposed four stereotyped characters which aim to evoke particular personality profiles (i.e., Poppy is outgoing/ extraverted, Spike is angry and argumentative, Obadiah is gloomy and depressed, Prudence is pragmatic and practical) (Figure 5). Focusing on extraversion and neuroticism, (Sevin, Hyniewska, and Pelachaud 2010) proposed heuristic rules to modulate the number of backchannel and the amount of mimicry according to personality (Figure 5). They considered that extraversion leaded to more backchannel and neuroticism to be inversely related to the amount of mimicry. In (McRorie et al. 2012), authors suggest that past approaches about the modeling of synthetic personalities were largely based on intuitions from the designers. They advocate the necessity of a theoretical sound approach to ensure believability. In their paper, they choose the Big Three model of personality as a basis (Eysenck) because it is less descriptive and propose a biological foundation of traits (not purely lexical). For example, an extraverted person is "*less cortically aroused than introverts*" and thus should have high levels of general activation, perform more body movement with direct eye contact (Puppy character). Proceeding the same way for the three other characters, they proposed general behavioral style for face and gesture (Figure 5). Contrary to (Sevin, Hyniewska, and Pelachaud 2010), personality traits influence general behavioral style and not interactive variables (e.g. mimicry). The evaluation based on videos shows that participants attributed the intended personalities to the various characters. The first limitation of this approach is the joint use of

stereotyped physical appearances and behavioral styles which makes difficult the analysis of the contribution of behavioral styles alone. In their evaluation, participants were already able to recognize personalities from still images, nonverbal styles confirming this attribution. In (Bevacqua et al. 2012), an evaluation is carried out controlling for the physical appearance, and asking participants to judge personalities after an interaction phase: participants did not attribute the personality characteristic researchers aimed at. These complementary results highlight the difficulty to associate personality traits with interactive behaviors.



		Preference	Frequency	Speed	Spatial volume	Energy	Energy	Repetitivity
Poppy	face gesture	high high	high high	Poppy high	high high	medium medium	medium medium	medium high
Spike	face gesture	medium high	medium medium	medium medium	medium medium	high high	medium low	high high
Prudence	face gesture	medium medium	medium medium	medium medium	medium medium	medium medium	medium medium	medium medium
Obadiah	face gesture	medium low	medium medium	low low	medium medium	medium medium	low low	low low

Figure 5: The four characters proposed in the SEMAINE project, the rule-based design of interactive behaviors according to neuroticism and extraversion and heuristic rules to discriminate behaviors of the four characters (BC = backchannels)

Lastly, another empirical approach for the definition of nonverbal behaviors as a function of personality characteristics is proposed in (Ravenet, Ochs, and Pelachaud 2013): a web application asks participant to select the nonverbal features (gaze, head movement and gestures) they best associate with one type of interpersonal attitude ("*state of mind*" rather than general way of behaving).

Users' personality in interacting with IVA

Instead of modeling personality in lifelike agents, some research works focus on the influence of user's personality in interacting with computer systems. For example, (Kang et al. 2008) found that more agreeable people felt greater rapport while interacting with a rapport agent endowed with backchannel and postural mirroring. With this same rapport agent, (Pütten, Krämer, and Gratch 2010) found that social presence and rapport are better predicted by the Big Five traits than by the presence of backchannels. The work form (Buisine and Martin 2010) focus on extraversion in embodied conversational agents. They found that all users but female introverts were impacted by a virtual tutor with various non-verbal behaviors. A recent study proposed to use personality traits of the user to improve the prediction of the evaluated experience (quality of the interaction with a virtual listener): the best result to predict the interactive experience was obtained by combining nonverbal features and personality traits from the Big Five model, with an average percentage of variance explained of 30% (Cerekovic, Aran, and Gatica-Perez 2014).

Personality relevance as a function of the task

The design of "*appropriate*" personality profile for virtual agents might be guided by several considerations. As already mentioned, the similarity-attraction hypothesis argues that the virtual agent should match the user personality to foster attraction and likeability (Nass et al. 1995). As most personality models follow the immutable aspect of personality and influences behaviors regardless of the context, (Poznanski * and Thagard 2005) proposed to provide more adaptability to the agent by including personality changes based on the influence of the environment (Table 3).

Situation encounter	Effects on personality
Friendly	*more* Extroverted AND *more* Agreeable *less* Introverted AND *less* Disagreeable
Hostile	IF Disagreeable THEN *more* Disagreeable IF Introverted THEN *more* Introverted ELSE randomly *more* Disagreeable OR *more* Introverted ALSO *less* Extroverted AND *less* Agreeable
Explore	*more* Open
Persist	*more* Conscientious
Stressful	*more* Neurotic

Table 3: effects of the environmental context on personality in (Poznanski * and Thagard 2005)

At a more applicative level, (Mairesse and Walker 2010) provided interesting suggestions about personality profiles adapted to various tasks such as tutoring or telesales systems (Table 4).

Task	User type	System adaptation policy
Information presentation system	Novice	Extravert, agreeable
	Experienced	Converge towards user
Tutoring system	Any	Extravert, agreeable, conscientious
Telesales system	Any	Potent (extravert), match the company's brand
Video games / entertainment	Any	Character-based
Crucial information retrieval (e. g. finance)	Any	Conscientious, not extravert, not agreeable
Psychotherapy	Fearful (introvert, not open)	Aggressive (extravert, psychotic)
	Aggressive (extravert, psychotic)	Fearful or aggressive
Psychotherapy training system	Any	Neurotic
	Any	Aggressive (extravert, psychotic)

Table 4: Suggestions of advantageous personality profiles for specific tasks (Mairesse and Walker 2010)

1.1.3. Summary

Overall, this review of the state of the art shows the pervasive presence of personality oriented works in computer sciences. While various research questions and approaches have been explored, several limitations related to this thesis came out. First, and although some researchers in Affective Computing highlighted the richness of various model of personality in psychology (Clavel and Martin 2009), 95% of the existing literature on personality focuses on the Big Five models or alternative models which are linear combinations of the Big Five (Big Three or HEXACO) (Callejas, Griol, and López-Cózar 2014) (A. Vinciarelli and Mohammadi 2014). Based on a lexical approach, this model is hardly connected to interactive behaviors and underlying motivations. An alternative to a purely descriptive approach is to consider personality approaches which propose models of underlying processes which drive social behaviors. (Nass et al. 1995) interpreted extraversion and agreeableness from the Big Five with the interpersonal circumplex model of personality, extraversion being an expression of warmth and extraversion and expression of dominance. This was one of the few attempts to consider interpersonal theories of personality (A.G.C. Wright 2014). In (Faur et al. 2013), authors advocate the usefulness of the consideration of socio-cognitive theories of personality which provide models about the origin of behaviors. They specifically focus on self- regulation strategies dedicated to aligning desires with reality. Another limitation of this literature is the small amount of projects which deal with nonverbal interaction, especially the full body. Most of the works consider a unilateral aspect of personality: the recognition, the perception and the modeling of expressive behavior of personality independently of reactive behaviors. These two limitations taken together encourage us to look beyond the Big Five in process oriented approaches which are inherently related to social interactions.

In the following, we review works conducted in computer sciences which primarily focus on interactive processes: social coordination and empathy.

1.2. Nonverbal interaction in computer sciences

1.2.1. Early works and heuristic mimicry

The necessity to endow computer systems with social interactive abilities has been quickly identified after the pioneer works from (Reeves and Nass 1994). Cassell and colleagues advocated that "*nonverbal behaviors related to the processes of conversations, what we call envelope feedback is much more important than other feedback, such as emotional expression*" (Cassell and Thorisson 1999). With this concept of envelope feedback, they directly addressed the importance to focus on the nonverbal interdependence within the interaction rather than the content of the communication. Their experience confirmed the importance of feedbacks with good timing compared to emotional expression in the evaluation of the system. In the domain of teleconferencing, (Watanabe, Ogikubo, and Ishii 2004) considered the importance of nonverbal "*entrainment*": in an avatar mediated communication paradigm, they enabled individuals to spontaneously synchronize their respiration by means of avatars representing explicitly their breath. Since, several teams have evidenced the positive outcomes (e.g., likeability) of various types of social coordinations. In (Bailenson and Yee 2005), authors manipulated the amount of mimicry of a virtual human (in head nods) during an argument and found. The mimicked participants found the virtual agent more persuasive and received more positive traits attributions. In order to be effective, mimicry should be "*appropriate*" in amount and timing (Leander, Chartrand, and Bargh 2012). In a second study, Bailenson and colleagues showed that their automatic "*algorithmic*" mimicry was not detected by participant evidencing the possibility to endow virtual humans with "*implicit mimicry*" abilities (Bailenson et al. 2008). In the domain of crowd simulation, (McDonnell et al. 2009) showed how participants are highly sensitive to desynchronization between virtual humans. The Rapport Agent is a project which build on the theory of rapport from (Tickle-Degnen and Rosenthal 1990): the quality of the relation is function of three variables which are mutual attentiveness, positive expressions and coordination. Rapport

in relationship as important implications: it facilitates negotiations, teaching management, caregiving, and therefore is valuable to be established for a conversation agent.

Lowering of pitch	➔	head nod
Raised loudness	➔	head nod
Speech disfluency	➔	posture/ gaze shift
Speaker shifts posture	➔	mimic
Speaker gazes away	➔	mimic
Speaker nods or shakes	➔	mimic

Table 5: feedbacks, mimicry and attention rules of the Rapport Agent in (Gratch et al. 2006)

In an attempt to build a feeling of rapport with a virtual human, Gratch and colleagues endowed a virtual human with these three abilities (Table 5) in a conversational task (Gratch et al. 2006). Participants have to watch a cartoon and then describe it to the listening agent. In the active feedbacks condition, participants spoke longer to the virtual agent, the social coordination helping the fluency of the interaction.

In a following study, they evidenced the importance of contingency of feedbacks compare to a random conditions of feedbacks behaviors for creating rapport (Gratch et al. 2007). Lastly, when systematically manipulating the three aspects of rapport, they found that more mutual gaze without positivity and coordination is perceived negatively (N. Wang and Gratch 2010).

Together, these researches have made it clear that mimicry and synchronized movement are essential in human agent relation and foster the effectiveness of the interaction. Since, some studies focused on the development of rapport on the long term: the more the relation is developed, the more the coordination aspect of rapport is important compared to positivity (Cassell, Gill, and Tepper 2007),(Papangelis, Zhao, and Cassell 2014). Robot for autistic children are endowed with social coordination abilities to establish a relation with the child (Kozima, Michalowski, and Nakagawa 2009). In the domain of remote collaboration, the possibility for partners to be spontaneously coupled is essential for shared understanding. Providing cues of eyes movement and physiological signals, (Chanel et al. 2013) highlighted the impact of coordination on emotion management and convergence. Lastly, (Bevacqua et al. 2014) conducted an experiment based on a theatrical game involving the imitation of slow upper-body movements and the proposal of new movements by the user and virtual agent. They measured self-report of coupling, co-presence, engagement, and believability and found that coupling was associated with co-presence, and engagement.

1.2.2. Development of data-driven interactive behaviors

An important shift in the domain has been the increasing reliance on collected behavioral data for the modeling of interactive behaviors (Sun and Nijholt 2011). (Huang, Morency, and Gratch 2011) proposed such a data driven approach: they identified three type of nods in a corpus of conversations and build a prediction model of these backchannels. This new approach performed twice better in eliciting rapport and interaction naturalness compared to the heuristic based model. Focusing on mimicry, (Sun, Lichtenauer, et al. 2011) built a database of 54 conversations with two scenario: an argument conversation to study agreement mimicry and a role playing game to study affiliation mimicry. In this case, mimicry is annotated as binary: mimicry is present or absent. Logically and in parallel, other researchers investigated the possible measurement of the social coordination phenomena. One line of research focus on the automatic detection of mimicry in existing corpus (Sun, Nijholt, et al. 2011). (Michelet et al. 2012) developed successfully an unsupervised approach (based on correlations and dynamical time warping as similarity measures) to measure immediate synchronous imitations between two partners within a window of 3 seconds. The model was trained and evaluated on a non-spontaneous corpus of gestures which limit its validity. (Bilakhia, Petridis, and Pantic 2013) took as the training corpus the database proposed in (Sun, Lichtenauer, et al. 2011). Using a long short term memory network (neural network model) that can preserve long range dependencies, authors present promising results obtaining 77.5% of positive recall of imitations. This paper is the first attempt to continuously detect behavioral mimicry from natural interaction data.

1.2.3. The measurement of synchrony

While works on mimicry focus on the similarity of behaviors in shapes and configurations, another line of research focus on the analysis of synchrony which is the coordination in time of behaviors (not shape and modality constrains) (Emilie Delaherche et al. 2013). The phenomena of synchrony have been previously investigated in non-social context such as with a drumming robot endowed with the ability to display rhythmic movements (Crick, Munz, and Scassellati 2006). It is more recently that some researchers paid more attention to the measurement of the social aspect of synchrony. (Reidsma et al. 2010) advocated the use of time lagged window cross correlations to investigate synchrony in naturalistic data. In (Emilie Delaherche and Chetouani 2010), participants performed a cooperative tasks of building a clown character. Based on audio features (e.g., pitch) and video features (e.g., motion energy), authors computed similarity measures based on correlation (temporal domain) and magnitude coherence (frequency domain). With a sliding time window of 1 second, they found evidence of synchrony in most of the features. A recent review of the existing literature across discipline about interpersonal synchrony have been proposed in (E. Delaherche et al. 2012). They contributed to the clarification of the concept of synchrony:

- The important element is timing rather than the nature of the behaviors
- Synchrony and mirroring can occur simultaneously
- Synchrony differs from mirroring as the adaptation various modalities for the two partners

Reviewing the existing methods to measure synchrony, they distinguish between manual annotation methods, automatic descriptive methods (cross correlation, recurrence analysis and frequency coherence) and automatic predictive models of synchrony. Within this last category, few works are available apart from those already cited earlier which do not really continuously predict synchrony but rather timing of pre-defined movements (prediction of backchannels: (Huang, Morency, and Gratch 2011); prediction of head mimicry: (Bilakhia, Petridis, and Pantic 2013)). Only one very recent paper investigate the possibility to continuously predict adaptation of body movement (Yang, Metallinou, and Narayanan 2014). Based on the USC CreativeIT database which is a goal driven improvised interactions with full body motion capture, they proceeded in two step to build their prediction module. First they investigated by means of window cross correlations of various full body features the degree of multimodal synchrony: this phase enabled authors to select "*target*" variables to be predicted. In a second step, they applied a Gaussian mixture model based statistical mapping automatically predicting this target body features of an interacting participant from the speech and gesture behavior of an interlocutor. The combination with a Fisher kernel framework outperformed other methods in terms of correlations and RMSE. While this approach is the only dealing with the full body and going in a detailed continuous analysis of body movement, no information is available about the naturalness the predicted movements would have: the predicted features are isolated variables (e.g., cosine of subject's body orientation angle toward the other) not articulated with a more global movement.

1.2.4. Theoretical models

In parallel to these various data driven approach to social interactions, some authors proposed models that go deeper in the consideration of theoretical models. (Kopp 2010) builds on the concept of motor resonance: concepts of mimicry or empathy are all "*fundamentally rooted in a sensorimotor basis in which fast perception-action links like the human mirror system actively involve the own motor system in the perception of other's action*". In their work, they attempt to build a resonant agent for gestures which has its own motor program activated when viewing a gesture from another. Unfortunately, no evaluation of the model is proposed. Similarly, (Prepin, Ochs, and Pelachaud 2012) modeled motor resonance (Figure 6) with an application to smile alignment. Smile can convey different stance, such as amusement or politeness, with different morphological and dynamics properties. In their model, they consider that both timing synchrony and nature of smile should occur jointly to foster reciprocal influence. For now, this interesting detailed model stays un-evaluated. Lastly, a preliminary work propose to model

turn taking inspired by dynamical models (Jégou, Chevaillier, and Loor 2014). Although promising, this body of works is at its early stage and would benefit from a tighter investigation of the Human Science literature.

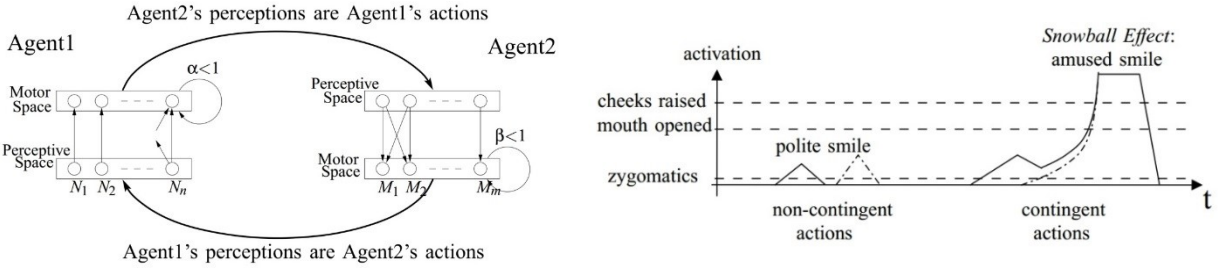


Figure 6: Motor resonance model and an example of smile alignment in (Prepin, Ochs, and Pelachaud 2012)

One remarkably absent notion in the study of social coordination in HCI is personality / individual differences. While some authors have already mentioned its essential role – "*One reason that not all interactions nor all speakers are equally amenable to mutual coordinations may lie in differences in the individual's "interpersonal sensitivity" as well as differences in the cooperative and social nature of the activity*" (Kopp 2010) –, few studies consider their influence on the interactive process. As already discussed, the SEMAINE project proposed four stereotyped characters with different personalities (McRorie et al. 2012), and (Pütten, Krämer, and Gratch 2010) evidenced the influence of the participant personality (i.e., agreeableness trait) on his/her evaluation of the relationship. But no project investigated the potential role of individual differences in interpersonal visuo-motor coordinations.

1.3. Empathy in computer sciences

1.3.1. Early works and care agents

The other phenomena inherently interpersonal and considered in computer sciences is empathy. While most of the research effort in affective computing focused on individual oriented problems (e.g., emotion recognition or emotion expressions synthesis towards a single user), some authors investigate affect sharing related processes. One of the first work proposing a computer system affectively responding to human affect comes from (Klein, Moon, and Picard 2002). These authors proposed an agent providing affective feedback via a text message to reduce negative affect during a frustration episode. While not being literally empathy, this work highlighted the importance of affect sharing/exchanging in HCI.

The interest in building "*agents that care*" appeared slightly later with the presentation of the application "*FearNot!*": an application about bullying behaviors where the child acted as an invisible friend to a victimized character (Paiva et al. 2004). In this paper, authors argue that empathy is another important aspect that can lead to believability along with autonomy and personality for example. They distinguished two goals with their lifelike agent: endowing the character with empathic behaviors and with behaviors which trigger empathic reactions from the user. Based on the OCC framework, the agent can recognize the child emotion and respond affectively. Another care agent type has been proposed by (Bickmore and Picard 2005) where empathy is viewed as a way to reduce social distance. The approach to consider empathy as an affective reaction integrated in an emotional framework such as OCC has been followed by several other works. (Ochs, Pelachaud, and Sadek 2008) remarked that the OCC model has only two empathic response (happy-for and sorry-for) and proposed to open to all other emotions (e.g., angry-for). (Aylett et al. 2009) developed an OCC model with empathy for inter-cultural education application. The study of the type of empathic feedbacks to deliver has been the subject of different works. In the care agent system for educational purpose proposed in (Prendinger and Ishizuka 2005), the user faces two agents: one which leads an interview and ask

unpleasant questions, and another which address the negative emotions of the user (detected via physiological signal). According to the emotion detected, this second agent can express the appropriate empathic reaction such as empathy, encourage, ignore and congratulate (Table 6). In their setup, they showed that empathic feedbacks had a positive effect on the interviewee's stress.

Actions	Example Response
Slow Empathy	The agent displays concern for a user who is aroused and has a negatively valenced emotion, e.g., by saying "I am sorry that you seem to feel a bit bad about that question."
Encourage	If the user is not aroused, the agent gives some friendly comment, e.g., by saying "You appear calm and don't have to worry. Keep going!"
Ignore	The agent does not address the user's emotion, and simply refers to the interview progress, by saying, e.g., "Let us go on to the next question."
Congratulate	If the agent detects that the user is aroused in a positive way, it applauds the user ("Well done!", "Good job!", "You said the right thing" etc)

Table 6: the four possible appropriate responses for the care agent in (Prendinger and Ishizuka 2005)

These empathic responses from care agents have been shown to have various positive outcomes in the experience of the interaction. In a BlackJack application, (Brave, Nass, and Hutchinson 2005) found that a virtual agent show other-oriented emotions (through face and text) increased felt care, trust and liking. More recently, a robot companion endowed with empathic responding had a positive effect on the perception of the robot (Leite et al. 2012). More specifically, an adaptive responding (responding only to negative affect) had a positive effect whereas a random empathic responding had an inverse negative effect. In a following study, the same authors found the empathic robot were judged as friendlier (Leite et al. 2013). In an immersive story-based learning, a virtual character is endowed with empathic abilities (text-based) in order to "*transport*" the student in the story (McQuiggan, Rowe, and Lester 2008). In the empathic responding condition, students reported more presence in the virtual environment. Also, this study is the only to consider individual differences in empathic dispositions of participants: greater empathic dispositions were related to more presence through greater sensibilization to the empathic responding.

1.3.2. Models of empathy

Overall, the previous works implemented empathy as an other-oriented emotional response with successful positive outcomes. However, little is explained about the process leading to empathy, the affective response being defined heuristically. An alternative have been to directly ask users the expected responses. To design empathic expressions for conversational agents, (Niewiadomski, Ochs, and Pelachaud 2008) conducted an evaluation study where participants were asked to identify the most appropriate way to express empathy. They could choose between simple (facial expression of one emotion) and complex (superposition of several emotions), and between egocentric emotions and empathic emotions. Complex emotions with superimposed egocentric and empathic reactions were found to be the most appropriate. Also in an experimental approach to define appropriate empathic responding, (McQuiggan and Lester 2007) proposed a data driven affective architecture and a methodology for learning empirically informed models of empathy from observations of human to human interactions. In a first phase (training phase), one trainer is the target in first person and another individual is the empathizer in third person which define the affective reactions that the target should have in the situations. Authors argued that such an empirical approach is necessary as the study of empathy is too recent in psychology (no consensus).

Several research projects focused more specifically on the empathic process and proposed computational models which account for the detailed mechanism of empathic responding. Building on recent findings in neuropsychological theories of human empathy, (S.H. Rodrigues et al. 2009) considered empathy as a process grounded in the perception-action model. Before an empathic response occurs, they define two parallel processes: an emotion recognition track and a self-projection appraisal in the situation of the other (from who the emotion

recognition process is apply) (Figure 7). The emotion elicited via self-projection is compared to the candidate emotions and similarity lead to empathy. To account for the fact that people do not always empathize, they introduce modulation factors which are: personality, similarity, mood and affective link. In this framework, personality is defined as the "*agent's resistance to feel certain emotions*" and the affective link as the "*social bonds between the two persons*". In two studies, authors found the empathic respondant to be evaluated more likeable, caring, and trustworthy (Sérgio Hortas Rodrigues et al. 2014).

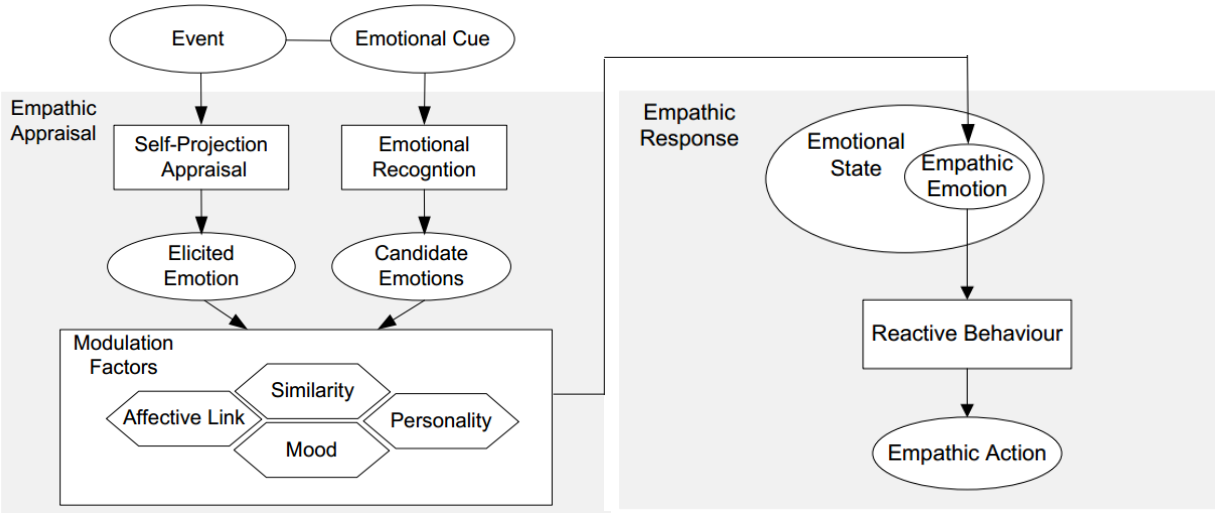


Figure 7: empathic process model proposed by (S.H. Rodrigues et al. 2009)

If the model from Rodrigues and colleagues insists on the vicarious aspect of empathic responding, the approach proposed by (Boukricha, Nguyen, and Wachsmuth 2011) focus on the self-projection process alone. They used a scenario of tower building with the virtual agent helping in the task. The helping actions are triggered and modulated by its degree of empathy.

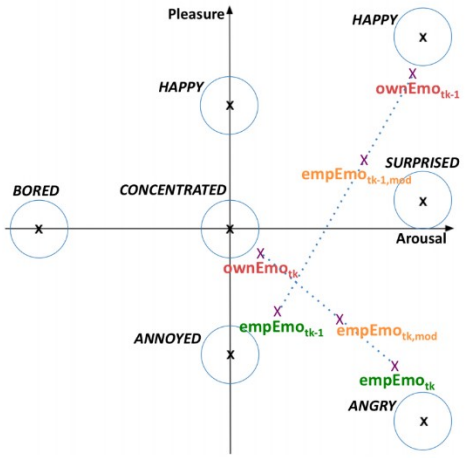


Figure 8: example of emotion moderation according to the empathic self-projection in (Hana Boukricha, Nguyen, and Wachsmuth 2011)

The empathic process features three steps: first the empathy mechanism is the generation of and empathic emotion related to the appraisal of the situation of the other. In this view, empathy is equivalent to situational perspective taking (embodied simulation). In a second step, this empathic emotion is modulated by the agent mood (addition of the values in a dimensional emotional space), liking and deservingness (Figure 8). In another study, the same model provides empathic responding based solely on the facial expressions of the other (the agent infers the emotion from the action units) (Boukricha and Wachsmuth 2011). The authors observed that participants watching the empathic agent expressing modulated empathy toward another agent perceived as expected the empathy process (Boukricha et al. 2013).

Lastly, (Janssen 2012) offered a more descriptive and integrative view of empathy identifying three major components: cognitive empathy (ability to infer what another is feeling), emotional convergence (ability to experience another person's emotions) and empathic responding (response to another person's distress consisting of

sympathy or personal distress) (Table 7). Although being comprehensive and useful to guide future research, the main limit of his contribution is the lack of articulation between the three components: "*the precise interaction between empathic responding and the two other components of empathy is not entirely clear*". A really interesting point made in the paper is the closeness between the concepts of emotional convergence and synchrony: the author review some of the method to traditionally measure synchrony for their use in emotional convergence.

Component	Related concepts	Automated measurement	Example applications
Cognitive empathy	Theory of mind, mentalizing, empathic accuracy	Classification of facial, speech, posture, or physiological signals into emotion categories	Affective music player Emotionally adaptive games Emotionally intelligent cars
Emotional convergence	Mimicry, motor empathy, emotion matching, imitation	Synchronization analysis between expressions of two or more individuals	Closeness measurement Communication evaluation Scientific empathy measurement
Empathic responding	Sympathy, personal distress	Detection of specific nonverbal behaviors or thresholding emotional convergence indices	Empathic conversational agents Automated behavior coaches Helpdesk support system

Table 7: description of the three major component of empathy according to (Janssen 2012)

1.3.3. Summary

Overall, this review of the study of empathy in computer sciences evidences a raising interest in the integration of empathic responding abilities in social agent in order to foster positive outcomes in interactions. However, several limitations are critical for the goal of this thesis. First, individual differences in empathic responding are rarely considered with only one study actually providing results of the influence of users' empathic dispositions (McQuiggan, Rowe, and Lester 2008). Another limitation is the lack of bodies in the treatment of empathy in computer sciences. While some papers mention the association with the perception-action model (and therefore the motor resonance origin of the phenomena), no one proposed a kind of motor empathic resonance. Efforts are more often toward the integration of empathic model into complex architecture such as the OCC model which emphasizes the cognitive aspect of social interaction (as an appraisal process).

1.4. Conclusions

From this review in three parts of the Computer Science literature, we can draw several conclusions to guide the following ofthis PhD thesis. First, individual differences are considered only under the framework of the Five Factor model of personality. Being general and descriptive in nature, it appears to be difficult to draw hypotheses linking its traits to interactive nonverbal behaviors. Instead, process or motivational approaches to personality could probably be more helpful in highlighting the driving force of social behaviors (instead of the mere description of consequences).

Secondly, we found quite few attempts to model a full body interaction with continuous mutual adjustments, with the vast majority of studies proposing some heuristic implementations of mimicry. The development of listeners' head movements concentrated efforts on faces which appear less complex to coordinate than a full body (given the smaller number of degree of freedom in virtual faces). Another potential reason is perhaps the lack of considerations of the essential role of interaction and movement in social relationship: adaptation through mimicry is implemented in order to improve rapport. However, as highlighted in the introduction, the interpersonal continuous interaction is probably constitutive of social cognition and fosters intersubjectivity. As many researchers are interested in setting a common ground between the user and the IVA and inducing a sense of presence, the implementation of tightly mutual movement adaptations should be the first place to look at.

Thirdly, whether it is in the study of personality, nonverbal interaction or empathy, a common trend in Computer Sciences is to move on from model based on heuristic rules to data-driven approaches. Although it provides a stronger experimental ground to future generated models, it cannot avoid to consider theoretical models related to the studied phenomena for several reasons. In a data-driven approach to the modeling of behaviors, the researcher has to define the task and the way to collect behaviors, which variables to compute (feature extraction) and how to select the most relevant to have the most efficient and parsimonious model (feature selection). All these choices are not theory free and the defined theoretical ground will guide the research through those steps.

Finally, we noted the tendency of works in IVA to go more integrative, including more modalities (multimodal works are encouraged), more psychological phenomena (e.g., emotion, personality, motivations, beliefs) in fairly complex high level tasks (e.g., dialogs). Given what we previously acknowledged, the focus on more minimalist task with fewer variables interplaying would enable a further investigation of theoretical aspects. In our view, the success of virtual listener is partly due to the minimalism of the task: a head listening (no speech) to a user. This same approach could hold for full body interaction in a first step, before going into more complex tasks.

Together, this review encourages us to investigate the state of the art in Human Sciences related to the same three parts of the previous section: bodily interpersonal processes, empathy and individual differences focusing on the issue of social bonding.

2. HUMAN SCIENCES

2.1. Social interaction and interpersonal coordination

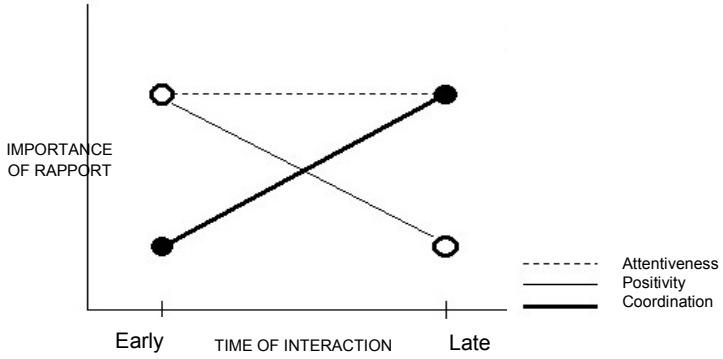
2.1.1. Early findings and field structuring

The development of conversational analyses in the early 70s associated with video recording possibilities enabled the analysis of dyadic social interactions in ecological situations (W. S. Condon and Ogston, 1966). First observations evidenced reciprocity phenomena like interpersonal coordinations at the verbal and bodily levels, as for example in the pioneer work of (Scheflen 1964). Three lines of research emerged from these findings (Chartrand and Bargh 1999a): the study of synchrony in time of verbal and nonverbal behaviors (W. Condon and Osgton 1971), the study of body configuration matching for example in posture (LaFrance 1979)(LaFrance 1982) and the study of facial mimicry (Dimberg 1982). In the context where nonverbal communication was gaining increasing interest, notion such as synchrony, mimicry, convergence, entrainment and others reflecting a mutual influence of partners are used interchangeably without clear operational definition. Positive social outcomes such as rapport were associated with postural mirroring (LaFrance 1979), movement coordination (Bernieri 1988)(Kendon 1970) and mimicking was hypothesized to enable partners to share their point of view (Scheflen 1964).

A first broad and integrating definition of coordination phenomena was proposed by (Bernieri and Rosenthal 1991): "*Interpersonal coordination is the degree to which the behaviors in an interaction are nonrandom, patterned, or synchronized in both timing and form*". The essence of such a definition of coordination is the idea that partners are mutually responsive (Cappella 1997). From this definition, authors propose to distinguish *behavior matching* phenomena which occur when two people show similar body configurations from *interaction synchrony* which occur when two people show alignment in time of behaviors.

A first model to account for the relationship between interaction and interpersonal outcome, the so called coordination – rapport hypothesis, was developed in the review from (Tickle-Degnen and Rosenthal 1990). They

defined the experience of rapport as resulting from the dynamic interplay of mutual attentiveness, positivity, and coordination. They also propose that these components are differently weighted over the course of a developing relationship with positivity being more important in early relationships and coordination being more prominent in developed relationships (Figure 9). While (Cappella 1990) raised some methodological concern about this conceptualization (ask how positivity can be empirically distinguished from positive outcomes such as rapport), rapport stayed the concept best associated with the quality of a social interaction. It has been shown it can either be evaluated by judgment methods or manually coded behavior co-variations (Cappella 1997).



From these advances, (Izard 1990) suggested that a promising line of research would be to study the social moderator of rapport such as personality, while (Ickes et al. 1988) outlined the necessity to consider the concept of intersubjectivity to understand the essence of such social phenomena. As it will be showed later in this section, only the first author's perspectives were followed by research works.

Figure 9: Rapport model from (Tickle-Degnen and Rosenthal 1990).

During the same period, various interaction theories were proposed. One of the first and most influential interactive theories was the equilibrium theory proposed by Argyle and Dean (Argyle and Dean 1965). This theory focused on how individuals maintain an appropriate level of behavioral intimacy in interactions. Over the course of any interaction, they suggested that individuals adjust their nonverbal behaviors to maintain a balance in the level of involvement. Initially, the theory was operationalized for eye contact and proxemics, an increase in any of them leading to an increase in intimacy. If the situation made participants to stand nearer to each other, reducing eye contact would compensate to restore an acceptable level of intimacy. They extended the theory to include other behaviors such as body orientation, lean and touch. The main limitation of this adjustment theory is its consideration of compensation mechanisms only while reciprocation often occurs in friendly interaction (Patterson 2006). To account for these two possible mechanisms, a series of theories were proposed with arousal as a key mediator to the type of adjustment. For example, the expectancy-violations model from (Burgoon 1978) suggests that people are aroused when expectations about preferred levels of involvement in the interaction are violated. Low levels of violation lead to reciprocation whereas high levels to compensation. Alternatively, the arousal labeling theory from (Patterson 1976) stipulates that the experience of arousal in response to a change in partner's nonverbal behavior precipitates a "*selt-attribution process*". If the labeling process leaded to a positive emotion, then reciprocation occurred, but if discomfort arose, then compensation took place. Common to all these affect based theories is the issue that emotions are not present in every social situation, with the additional difficulty to evaluate a theory where the central construct (arousal) is difficult to measure. More in line with results from the coordination-rapport hypothesis, the communication accommodation theory considers individual goals as key elements to determine convergence or divergence in interpersonal behaviors (Coupland and Giles 1988). All these theories can be considered as communication theories, with the ambitious goal of including components such as context and individual goals to explain complex adjustment patterns in social tasks.

As these propositions become more integrative to explain human communication in a more general way, they lose contact with actual nonverbal behaviors which limit their predictive power in simple bodily interactions. The most recent model from this line of research, the parallel process model (Patterson 1995), illustrates this tendency to go more comprehensive (Figure 10).

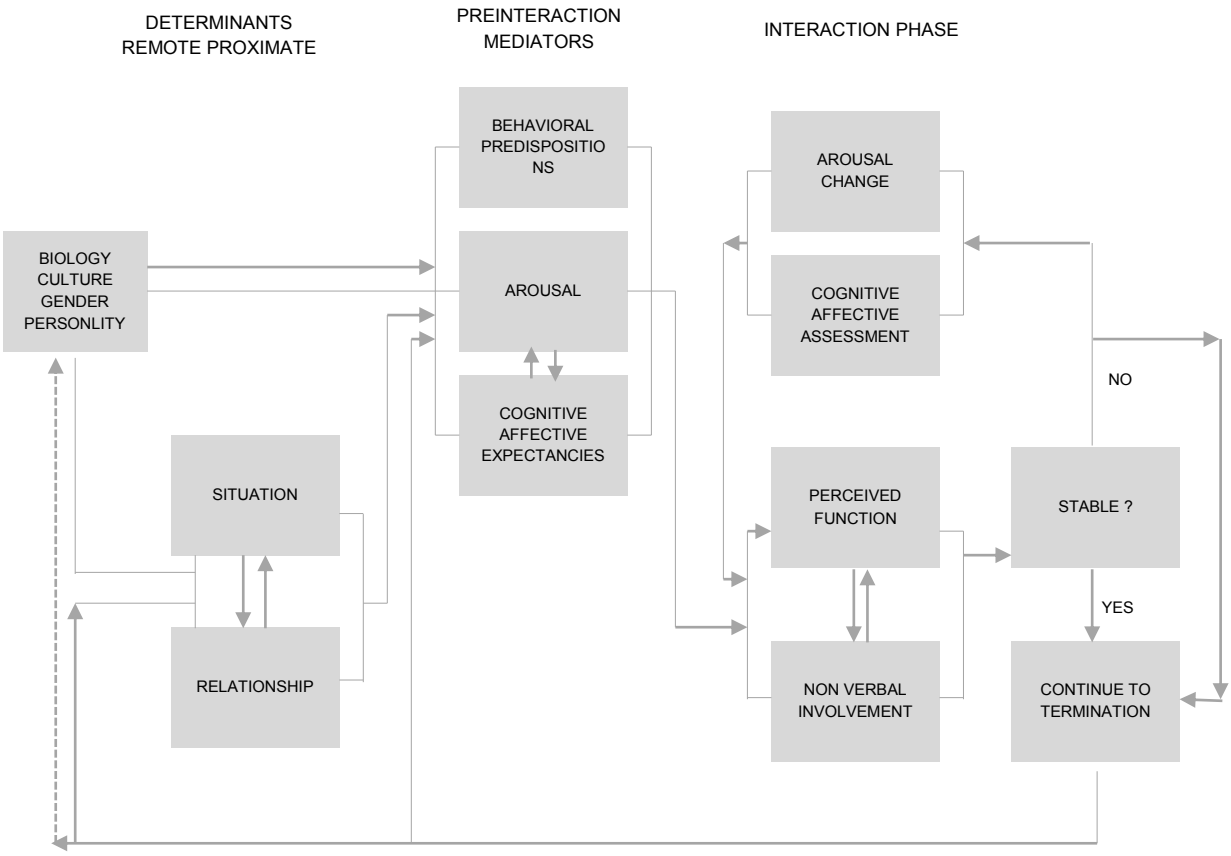
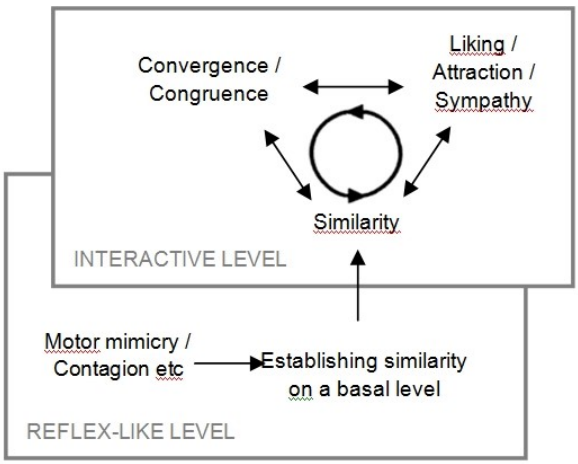


Figure 10: Parallel process model (Patterson 1995)

In an attempt "*to review some less well known theories and ideas concerned with the "exchange" aspect of nonverbal communication*", (Wallbott 1995) proposed to conceptualize these two approaches as complementary (Figure 11).



They represent nonverbal exchanges on two levels: a level with basal mechanism such as imitation, mimicry, affective empathy, synchrony and emotional contagion. These phenomena establish nonverbal coordination in an "*immediate and unconscious fashion*", and are considered to appear earlier in the ontogenetic development. The second level is more cognitive, with cognitive empathy and convergence as the main mechanisms. At this level, convergence is part of a triad with affiliation and similarity.

Figure 11: (Wallbott 1995) model of interpersonal processes

However, it is unclear in the proposed schematization how an accommodation theory which consider both convergence and divergence reactions would be articulated in this schema. While the author acknowledges the non-exhaustivity of the model which takes "*a king of 'people get together' stance*" (i.e., it considers only convergence mechanisms and not repulsive mechanisms), this theoretical contribution provided a first articulation of the various interpersonal processes concepts described in the literature.

With the unsuccessful attempts of interactive theories, most of the research in bodily interaction took a bottom up approach, taking as a starting point the first level described by (Wallbott 1995). As described previously, two basal interpersonal behaviors have fostered prolific separate line of research: behavior matching and interactional synchrony. These two lines of research focus on automatic unconscious behaviors arising spontaneously. An additional research topic emerged to account for more complex and intended coordinated behaviors: the study of joint action.

2.1.2. Behavior matching

The vast majority of the literature about automatic imitation takes as a primary hypothesis that the perception of another person's behavior creates a tendency to behave similarly (Chartrand and Bargh 1999a). Taking its source in the ideomotor theory emphasized in psychology by James (Shin, Proctor, and J 2010), this idea, the perception-behavior link, has been considerably strengthened with the discovery of "mirror neurons" (Gallese 2001). These neurons found in apes fire both when a behavior from a confederate is observed and when the same behavior is performed by the ape observer. Mirror neurons in the context of cognitivist psychology alimented a representational explanation of behavior matching: when an individual perceive a behavior from another, a representation of this behavior is activated facilitating the emergence of the same behavior from the individual. This theoretical paradigm enabled to unify in the same neural mechanisms a variety of phenomena which goes beyond spontaneous mimicry: it proposes an explanation for response facilitation effect, learning through imitation and action understanding (Rizzolatti, Fogassi, and Gallese 2001).

In a recent review of automatic imitation, (Heyes 2011) reports three phenomena considered as evidenced of automatic imitation:

- Mirror effect: detecting neurophysiological reactions in passive setups (major experimental paradigm in the study of emotional mimicry)
- Movement interference: revealing interference or noise in behaviors when performed in front of an incongruent behavior (corollary of the facilitation effect) (Blakemore and Frith 2005)
- Motor mimicry: detecting in naturalistic social situations co-occurring behaviors

In this section, we focus on the third aspect of automatic imitation as it considers the whole body in social interaction. Behavioral matching, motor mimicry or spontaneous imitation will be used interchangeably to refer to it. Behavioral matching occur when two peoples engage in the same behavior (static configural properties) within the same short time window (from 3 to 5 seconds) (Chartrand and Lakin 2013), with the additional constrain that the behavior should be not relevant to the task (Heyes 2011). Defined as such, behavior matching is distinguished from similar action in the context of joint action. Emotional mimicry probably relies on the same basic mechanisms as general automatic imitation, but with the increasing complexity to consider emotions (Hess and Fischer 2013). Largely focusing on facial reactions in a mirror effect experimental paradigm, the field of emotional contagion is not considered in this section.

In their seminal paper, (Chartrand and Bargh 1999a) coined "*chameleon effect*" the unconscious mimicry of posture and mannerisms of interaction partners. Underlying this label is the idea that mimicry serves the adaptive function of

facilitating social interaction. In an experimental setup with an experimenter mimicking a participant without his/her awareness, these authors evidenced for the first time the causal link that unconscious mimicry from various behaviors causes an increase in liking. From this finding, other authors suggest that the chameleon effect acts as a social glue to realize the universal need to belong (Baumeister and Leary 1995). In addition to acknowledge the consequence of spontaneous behavior matching, they investigated how dispositions in empathy would influence automatic imitation. As their experimental protocol does not involve any affect, they focused their effort on cognitive empathy: perceptive taking. They evidenced a significant association: having greater perspective taking tendencies is associated with more chameleon effects.

Following studies revealed a variety of moderators of unconscious behavior matching making of it a flexible phenomenon. Among them, the most relevant for this thesis are reviewed here. Building on recent development on the study of the construal of the self in the social sphere (Cross, Bacon, and Morris 2000), (R. B. van Baaren et al. 2003) investigated the role on independent self-construal (individual define themselves as being autonomous and have a context independent processing style) and interdependent self-construal (individual define themselves in terms of their relations with others and have a context dependent processing style). They evidenced that primed and chronical interdependent self-construal increased spontaneous mimicry, and primed and chronical independent self-construal inhibited it. Hypothesizing that spontaneous behavior matching leads to affiliation through an increase of the self as "*other-oriented*", (Ashton–James et al. 2007) showed that having a high interdependent self-construal not only leads to more spontaneous mimicry but also mediates the association between mimicry and affiliation. Following the idea that information processing style might influence the way we interact with others, (R. B. van Baaren et al. 2004) investigate the association of a more direct measure of context dependence processing style (field dependence independence) on behavioral mimicry. Whether measured by the embedded figure test or primed, field dependence was associated with more spontaneous mimicry in a bi-directional way. In (Cheng and Chartrand 2003), high self-monitoring individuals were found to more likely mimic a confederate only in situations which contain affinitive cues (interacting with a peer or a superior versus interacting with a stranger). Positive mood of the participant has also been found to be a facilitator of unconscious mimicry (R. B. van Baaren et al. 2006). The rationale behind this expected result is that mood serves as a signal, conveying information about the friendliness about our environment: a positive mood indicates no threat (the individual relies on heuristics in a more holistic processing style), whereas in negative mood, the environment is problematic and one need to be on guard, (the individual is more analytical with more control). If spontaneous mimicry is so flexible, the level of appropriateness of mimicry might vary. In (Leander, Chartrand, and Bargh 2012), authors show that mimicking is not always received positively. This evaluation was a function of "*implicit standards*" such as the type of the task (mimicking induced coldness in task oriented task with the opposite effect in an affiliative task) and the self dispositions (interdependent people felt colder if not mimicked whereas independent felt colder if mimicked).

In a review of the research domain, (Chartrand and Lakin 2013) provide a detailed list of the moderators of behavioral matching:

- Facilitators of mimicry: pre-existing rapport, goal to affiliate, individual differences in prosocial orientations (empathy, self-construal interdependence), similarity (similar opinions, shared knowledge) and mood
- Inhibitors: goal to disaffiliate (e.g. for outgroups) and individual differences in proself orientations (self-construal independence)
- Consequences: cognitive processing (field dependence and creative thinking), persuasion (mimicking increase persuasion power), self-regulatory ability, liking and rapport, helping behavior, interdependence and feelings of closeness, accuracy of emotion perception and reducing prejudice

Even if not reviewed here, it is interesting to note that the same flexibility has been evidenced for facial emotional mimicry. An increasing number of studies underline that emotional mimicry is sensitive to context cues such as competition/cooperation tasks, similarity or head/gaze orientation (Hess and Fischer 2013). Against a mere motor

resonance hypothesis, Hess and colleagues argue that emotional mimicry serve as a primary function to promote affiliation (Hess and Fischer 2014). Whether it is in emotional mimicry or behavior matching, the flexibility of automatic imitation/reaction is attributed to an associative learning process between sensory input and associated actions: "*When there is consistent co-activation between sensory and motor neurons, in time, these neurons become capable of mutual activation. When you wave your hand and you always see your hand wave, a direct link between the perception of a waving hand and waving it occurs. This in turn, due to sensitivity of both endogenous and exogenous stimuli in the mirror system, can lead to (pre)motor activity when we see somebody else move a hand. Importantly, this can also explain why we sometimes respond in a complementary way. If we learn in life that it is healthier to respond submissively to dominant people, and vice versa, the same mechanisms of associated sensory-motor couplings can explain these automatic complementary movements*" (R. van Baaren et al. 2009).

A surprisingly absent topic in the study of behavior matching in naturalistic situations is methodological issues. Perhaps because the same procedure is implemented for most of the researches when imitation is not controlled (video recording of interaction with manual coding of matching behaviors), it can also be due to the nature of the studies: most researchers investigate the effect of manipulated behavior matching from a confederate. However, several questions could be raised:

- What is a "*good match*" of behaviors in terms of configurations? All the reviewed studies discretize behaviors in labels (e.g. foot shaking) which makes the matching issue a binary problem (the label is present in both partner or not). One might ask if behaviors are encoded in such a symbolic way. Perhaps the computation of a degree of configural similarity would be an interesting approach.
- What is a "*short time window*"? No clear guidelines exist to determine if two behaviors are close enough to be matched. Following a representational account of imitation, a memory retention argument could be built but studies only investigated the role working memory load on the presence of spontaneous mimicry (van Leeuwen et al. 2009). Investigating time in behavioral matching also raises the question of lag: is the difference in time between two matched behaviors a variable of importance? It seems reasonable to hypothesize that the "*smooth meshing of interaction*" (Bernieri and Rosenthal 1991) requires spontaneous behavior imitations to be well aligned in time, leading to an increase in affiliative feelings.
- Behavior matching requires a symmetrical situation to enable the two bodies to take the same posture. This condition limits to some social situations the apparition of automatic imitation.

These methodological issues were more debated in HCI where automatic detection of mimicry is an active research topic. However as we already reviewed, no consensus exist neither for the form or the timing of imitation.

2.1.3. Synchrony

Broadly defined, "*sensorimotor synchronization is the coordination of rhythmic movement with an external rhythm*" (Repp and Su 2013). A consequent literature exists on the ability of human to synchronize to artificial movements such as metronome or music, but the focus of this section is on interpersonal synchrony. Originally coined by (W. S. Condon and Ogston, 1966) behavioral entrainment, the study of interpersonal synchrony has its history strongly bounded to the development of new measuring methodologies most probably because of the continuous nature of the phenomenon to be observed: "*synchrony is most accurately described as continuous social coordination rather than a discrete state communication*" (Harrist and Waugh 2002). (W. S. Condon and Ogston, 1966) proposed a pioneer approach in using a manual frame by frame coding of behavior evolution of two participants discussing. Highly time consuming, (Bernieri, Steven, and Rosenthal 1988) evidenced that synchrony can be reliably rated by human observers, exactly as rapport or behavior matching. This approach has been used in various context such as unacquainted interactions (Bernieri et al. 1996), conflict resolution (Drolet and Morris 2000), extensively in children's development (Harrist and Waugh 2002) and intercultural judgment of synchrony (Kimura and Daibo

2006). However, as stated before, such a global perceptual approach does not capture what make the essence of the concept of synchrony: "*the dynamic adaptation on the part of both partners*" (Harrist and Waugh 2002).

Only few authors undertook the tedious but more objective and continuous method proposed in (W. S. Condon and Ogston, 1966) to analyze synchronization in natural settings from videos. The studies made by Adam Kendon on kissing or group discussion are fascinating examples of the meticulousness necessary for such approach (Kendon 1970) (Figure 12).

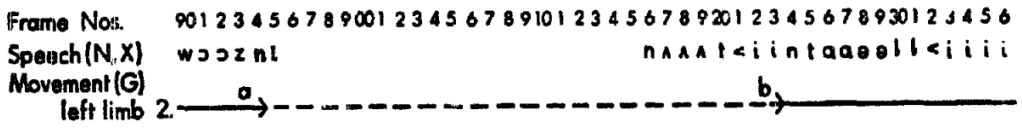


Figure 12: Manual annotations from (Kendon 1970)

The other line of research which produced most of the recent advances in interpersonal synchronization took its inspiration from two facts. Firstly, early mother-infant interpersonal synchronization studies regularly evidenced the cyclical pattern of coordination (Tronick, Als, and Brazelton 1977) (figure 13) (Leclère et al. 2014). Secondly, inspired by the self-organization principles of dynamical systems, intra-individual movement coordinations were found to be best modeled by the oscillating laws of a coupled pendulum (Haken, Kelso, and Bunz 1985). Dynamics is defined as the "*free interplay of forces and mutual influences among components tending toward equilibrium or steady states*" (Richard C. Schmidt and Richardson 2008). This second aspect is a shift in paradigm in the understanding of movement control: "*in order to answer how the many degrees of freedom of the perceptual-motor system are regulated, the traditional machine (i.e., neural or symbolic computational) theory answer was being replaced with a dynamical conception of order based on theories of physical biology. Neural wiring conceptions, such as the afference and efference distinction, were replaced by synergistic linkages between muscles that were dynamically constrained. Cognitive programs were replaced by equations of constraint that channel and guide a dynamic unfolding of behavior in a non-prescriptive manner*" (Richard C. Schmidt and Richardson 2008). Methodologically, this approach makes central variables characterizing the nature of the coordination between cyclical time-series. Coherence in the frequency spectrum and phase analysis are the main indicators of coordination.

Figure 13: Running correlations of infant and mother (Tronick, Als, and Brazelton 1977)

The dynamical system account of intra-individual coordination was soon transposed to intended visual interpersonal coordination for moving legs (R.C. Schmidt, Carello, and Turvey 1990). Three experiments highlighted the specific stability of in phase and anti-phase oscillations as well as typical phenomenon of physical dynamics in phase transitions: hysteresis, critical fluctuations and divergence. By focusing on one limb coordination, experimenters could more easily investigate the unfolding dynamics of movement adjustment in laboratory context. Using a minimalist wrist pendulum experimental paradigm (Figure 14), (R.C. Schmidt and O'Brien 1997) further investigated the impact of intention on synchronization. They described social interactions as cases of implicit coordination (not intended) thus weakly constrained, as opposed to dancing or aerobics where the explicit goal is coordination. Their results show that spontaneous entrainment occurred and that it can be modeled using the coupled oscillatory equations as in intended coordination. This result was confirmed in a subsequent study (M. J. Richardson, Marsh, and C 2005). The major issue concerning this approach is the ecological validity of the experimental protocol: making unrealistic movements, the generalization to more complex tasks is not

straightforward. To address this concern, (M. J. Richardson et al. 2007) proposed a rocking chair paradigm "*where the movement is incidental, but where the social context and mechanical constraints naturally pull one toward spontaneous rhythmic movement*" (Figure 14). The resulting patterns of coordination observed in two experiments demonstrated that the intentional and unintentional interpersonal coordination of rocking chair movements is constrained by the self-organizing dynamics of a coupled oscillator system. In an interesting methodological step backward, (R. C. Schmidt et al. 2011) proposed to analyze movement quantity during a knock-knock joke telling task using the dynamical framework. From video recordings of the interaction, perceived activity time series were estimated from raters on a frame by frame basis. Cross-spectral and phase analysis revealed greater spectral coherence and in-phase behaviors in the experimental condition compared to pseudo-interaction (randomly paired time-series). With the same approach, (Sadler et al. 2009) analyzed the coupling between perceived dominance and communion of dyads discussing about the personality of a character to come to an agreement. Results are in line with predictions made on the basis of interpersonal theories: reciprocity in dominance evolution (if one partner becomes more dominant, the other partner becomes more submissive) and reciprocity in affiliation (if one partner becomes more affiliative, the other partner becomes also more affiliative). One limitation of this last example is the absence of discussion of assumed stationarity in the analyzed signals: with the assumption of studying oscillating phenomena, most phase analyses are biased under such circumstances. Recent available methods in signal processing such as wavelet transform or cross-wavelet transforms are opening the door for such analyses (Issartel, Marin, and Cadopi 2007). Another proposed method for studying signals without distribution or stationarity assumptions within the dynamical framework was proposed in (Shockley, Santana, and Fowler 2003). Analyzing human postural sway, they implemented a cross-recurrence quantification analysis which enables researchers to determine the dynamic similarity in reconstructed phase space of system trajectories. Mainly, two indicators can be extracted to measure the amount and stability of the shared activity (Shockley et al. 2007). In the context of a cooperative tasks (to solve a puzzle), they evidenced for the first time interpersonal coordination of postural sway.

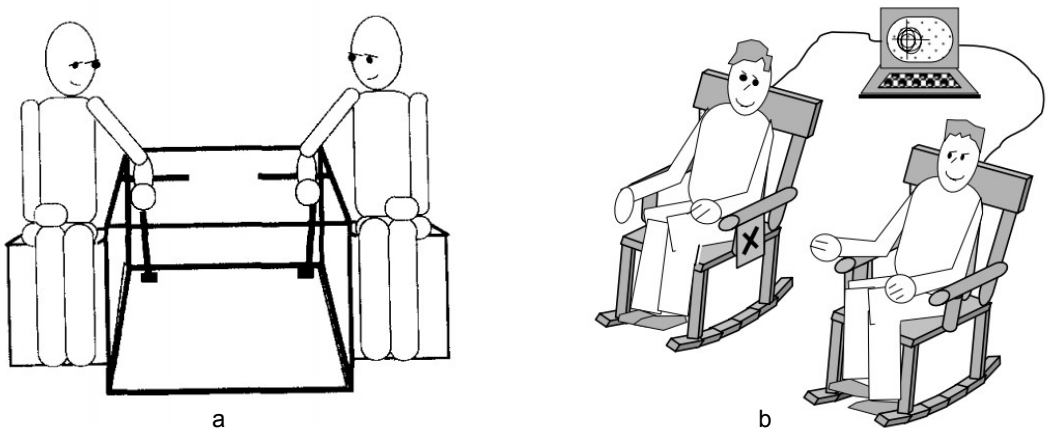


Figure 14: a) wrist pendulum paradigm (R.C. Schmidt and O'Brien 1997) b) rocking chair paradigm (M. J. Richardson et al. 2007)

Considering that interpersonal synchronization is cyclical in nature is a strong assumption. With the development of automatic video processing, the analysis of continuous stream of behaviors without strong constrains (minimalist setup or motion capture systems) was open more broadly to scientists from various backgrounds. The frame differencing method automatically computes the quantity of moving pixels between two frames of a video. With a camera adequately positioned, this activity might be meaningfully considered as a good indicator of overall activity (Paxton and Dale 2013a). The research group of Karl Grammer successfully applied this method to communication studies (K. Grammer et al. 1999)(E. O. & Grammer and Karl 2008). Compared to dynamical approaches or annotated codified repertoires, this approach is said to be a "*model free method which does not use any assumptions on the structure and organization of nonverbal behavior*". Using a linear approach to synchronization, the most

common method used in such naturalistic studies in windowed cross-correlations where the behavioral times-series are correlated to each other over a sliding window (E. Delaherche et al. 2012). Shifting times-series relatively to each other enables the analysis of lag within a correlation map (Ashenfelter et al. 2009). This method family evidenced a variety of spontaneous synchronization phenomena in therapy (Ramseyer and Tschacher 2006)(Figure 15) or conversations (Latif et al. 2014).

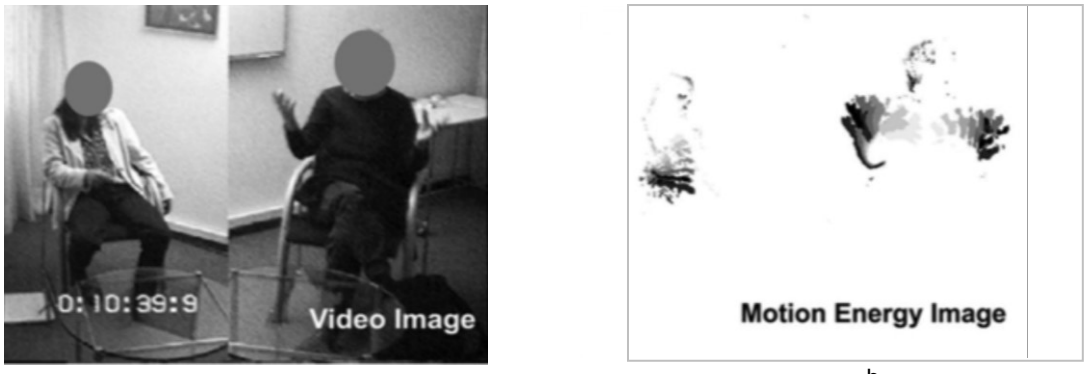


Figure 15: a) naturalistic conversation from (Ramseyer and Tschacher 2006) b) extracted motion energy

Whether or not to follow a dynamical approach to interpersonal synchronization is both a question of theoretical paradigm and type of task to be analyzed. In naturalistic settings, the dynamical framework is highly constrained with phase relative based methods such as cross-recurrence analysis which are more opaque than linear methods.

Contrary to behavior matching, synchrony is not constrained in terms of involved modalities: the head movement from one partner can be synchronized with the whole body movement of the other partner. A series of studies made explicit this inter-modality variability: (Sofianidis et al. 2012) found that synchrony patterns were more stable with somatosensory feedbacks, (Zivotofsky, Gruendlinger, and Hausdorff 2012) found that coordination during natural walking occurred in three different modalities (sound, touch and visual) and (Ramseyer and Tschacher 2014) revealed coordination of head and body within therapy sessions to be associated to different outcomes. Regarding the relative importance of one modality over the other, some contradictory results: in a wrist pendulum paradigm, (M. J. Richardson, Marsh, and C 2005) found coordination through the visual modality but significantly less in the verbal only condition whereas (Zivotofsky, Gruendlinger, and Hausdorff 2012) found sound and touch stronger channel to elicit synchronization in natural walking. Theoretically, these inconsistencies are not surprising given the variety of the task investigated: in (Zivotofsky, Gruendlinger, and Hausdorff 2012), authors explain that in outdoor environment visual attention should be paid to the environment, and that peripheral information such as auditory and tactile could be privilege for synchronization. More generally, synchrony might occur between combination of modalities in order to fit task constrains. Another possibility is the synchronization in one modality entrain other modality at the intra-individual at the same timing: (Codrons et al. 2014) found that when group synchronized their arm movement it induced a synchronization of respiratory control rhythms.

The various described approaches to synchronization are currently generating a "*burgeoning scientific literature*" (Lumsden, Miles, and Macrae 2014). As with behavior matching, various social moderators and consequences of synchronization patterns are evidenced. The most common finding in the literature of spontaneous synchronization is its bi-directional association with affiliation. Already highlighted in early studies (Bernieri 1988)(Bernieri et al. 1996), modern quantification of coordination confirmed the association. (Hove and Risen 2009) evidenced a causal link between interpersonal synchrony and affiliation by manipulating synchrony (experimenter move his finger in time or not with the participant). (Miles, Nind, and Macrae 2009) studied the evolution of felt rapport across all intermediary stage between in-phase and anti-phase synchrony: a clear gradation of rapport between the two attractor synchronization state (in-phase and anti-phase) was evidenced. Social bonding has also been investigated under

various angles. Inspired by the fact that organizations (e.g. armies) and communities (e.g. churches) often engage in activities that lead group members to act in synchrony, (Wiltermuth and Heath 2009) hypothesized that synchrony might strengthening group cohesion and foster cooperation. Across experiments where groups walked, danced or sing in synchrony before a task which test their cohesion, the hypotheses were confirmed: "*people acting in synchrony with others cooperated more in subsequent group economic exercises, even in situations requiring personal sacrifice. Our results also showed that positive emotions need not be generated for synchrony to foster cooperation*". (Reddish, Fischer, and Bulbulia 2013) add to this finding that shared intentionality of synchronizing movement enhance future cooperations. Entitativity is the experience of feeling with others as a group, as a coherent unity. (Lakens and Stel 2011) showed that synchrony induce both perceived rapport and entitativity, perceived and rapport entitativity being really close. At the level of the dyad, (Paladino et al. 2010) investigated the impact of synchrony on felt similarity. Using a synchronous multisensory stimulation (brushing the cheek of each participant as he or she is watching a stranger's cheek being brushed in the same way, either in synchrony or in asynchrony), they evidenced that synchrony leaded to an increase in the merging of self and the other (in terms of body sensations and face resemblance). (Valdesolo and DeSteno 2011) asked the question whether costly altruistic actions (more than cooperation) induced by synchrony might be due to a basic compassion response (itself mediated by an increase in appraised similarity). Using a taping task before observing a transgression, authors built a path model which confirms their hypotheses as well as showing that induced liking is a different effect of synchrony (Figure 16).

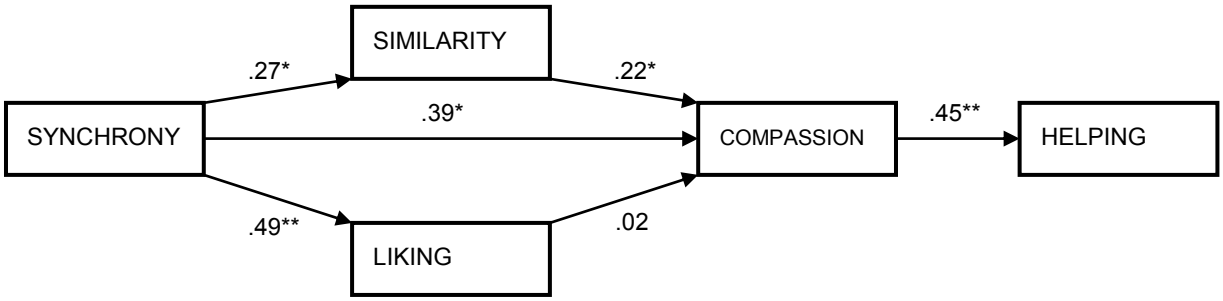


Figure 16: Path model from (Valdesolo and DeSteno 2011)

Two other consequences situated more at the individual level were found. (Macrae et al. 2008) manipulated the synchrony of the experimenter and evaluated the extent to which the participant remembered the facial appearance of the experimenter: synchrony was associated with more remembered cues. Based on the rationale that social interaction are vital to daily life (Baumeister and Leary 1995), (Lumsden, Miles, and Macrae 2014) investigated if synchrony would influence the self-affective experience. More specifically, self-esteem was the variable of interest as it has been conceptualized as a "*monitor*" of the quality of interpersonal functioning (people strive to protect self-esteem). The results showed an increase in synchrony induced an increase in self-esteem.

Individual differences were less studied than for behavior matching. In a dynamical approach to synchronization, (Nessler and Gilliland 2009) evidenced the influence of biomechanical individual differences: about 30% of the variance in synchrony was accounted by leg length of participants. The only study considering individual differences in the framework of dynamical system is an early one. Using the highly constrained wrist pendulum tasks, (R.C. Schmidt et al. 1994) identified the influence of social competence on oscillating entrainment: complementary dyads (one partner high in social competence with one partner low in social competence) generated more coordination than matching dyads (whether high or low in social competence). Authors hypothesized that in complementary dyads, a simpler coordination schema with one leader and one follower might have appeared giving clearer coordination patterns. Lastly, (Lumsden et al. 2012) found that pro-socially oriented persons (motivation to affiliate) had greater level of synchrony.

The last aspect which has been investigated as a moderator of interpersonal synchrony is the context. As noted in (Paxton and Dale 2013b), the vast majority of the literature on interpersonal synchrony focus on neutral or positively valenced task. With the aim of looking at the impact of a negative context on synchrony, (Miles et al. 2010) revealed that when a confederate simulated to being late to the experiment, participants showed diminished level of synchrony. (Paxton and Dale 2013b) compared an affiliative discussion and a conflicting discussion. The conflict was built by asking participant their opinion about a topic and choosing the one for which they disagree. Using frame differencing methods, they evidenced a strong decrease in synchrony during the argument task. The tasks had no influence on self-reported emotions (PANAS). Finally, (Tschacher, Rees, and Ramseyer 2014) also investigated the impact of different type of discussion on synchrony. Contrary to (Paxton and Dale 2013b), the competitive task (supposed negatively valenced) induced more synchrony than the collaborative task. This discrepancy can be interpreted as due to the difference in tasks: in this experiment, a list of argument was proposed and participant should convince the other of them (for the competitive task). This setup does not intimately engage individual to expose their own opinions, making this condition less disruptive than in (Paxton and Dale 2013b). As synchrony was found positively associated with positive emotion reported after the task, a possibility would be that the competitive task might have been experienced as a game inducing positive affects. The study of interactional synchrony across various emotional context is one of the future question to be assessed (Chartrand and Lakin 2013).

In terms of methodology, both approaches (dynamical and linear) have seen considerable development toward more fine grained, more systematic and less biased analyses. In the dynamical framework, the main issue concerns the non-stationarity of the signal: as most of the phenomena are highly non-stationary, new methods are proposed (e.g., wavelet transform). Being more complex, they open new study possibilities at the expense of analysis clarity. In the linear framework, one critical variable to adjust in windowed cross-lagged correlations is the window size. Early on (Boker et al. 2002) described the trade-off to do between sensitivity (the more the window is small, the more it is sensitive to little changes in lag evolution) and reliability (the bigger the window the greater the reliability). Consequently, if one is interested in the global synchronization during a task, the size window can be of the length of the task (no need for sensitivity). But as the purpose of synchronization analyses is the study on the mutual adaptation in time, a more sensitive analysis should be valuable. The choice of this time window appeared to vary according to the goal of the survey, from 0.5s (Latif et al. 2014) to 50s (Won et al. 2014). However, to our knowledge no studies provided a rationale for the choice of the time window. Finally, one common issue to both approaches is the definition of a ground truth against which to compare the experimental task. Early on (Bernieri, Steven, and Rosenthal 1988) introduced the concept of pseudo-synchrony which is the level of synchrony measured from mismatched dyads (when behaviors from participants from different dyads are used to compute synchrony). In a recent review of the question, (Ramseyer and Tschacher 2010) confirmed the validity of this approach: "*the paradigm of pseudointeractions has been applied to recent research and appears to be well-suited as an empirical control condition for nonverbal synchrony*".

Less strictly defined, the concept of synchrony has been applied to different type of associations (e.g. the synchronization of patterns in terms of complexity (Abney et al. 2014), different scales (e.g. in (R. C. Schmidt et al. 2014) synchrony was evidenced at different time scale of the joke task) and different domains (e.g. synchrony preference referring to the willingness to adjust one's agenda to others in organizations (Leroy et al. 2014)).

Overall, synchrony is a concept which gained increasing interest in the last decay, fostering development in methodologies and theoretical frameworks. As behavior matching, spontaneous entrainment appears to have various affiliative consequences. Induced self-other overlap was found to mediate the consequences of compassion and helping. And as behavior matching synchrony appears to be highly flexible: the context of the task and individual differences related to social bonding and affect modulated the emergence of synchrony phenomenon. (Chartrand and Lakin 2013) suggested that both serve the goal of interpersonal coordination more broadly, which facilitate and

regulate numerous complex social phenomena and put as a perspective to investigate the interplay of behavior matching and synchrony.

2.1.4. Joint Action

Unintentional behavior matching and interpersonal synchrony previously reviewed correspond to low level mechanisms assume to serve the function of social bonding. Two major theoretical paradigms underlie their conventionalization and operationalization with only few explicit confrontations of hypotheses under the same task. One of these few examples is (Romero et al. 2012) were authors proposed an explanation of the motor interference effect with a dynamical approach: rather than assuming that interference was due to an incongruence in activated representations, they revealed that the increased fluctuation in movement while observing an incongruent one could be model as a cyclical entrainment. Apart from these rare studies, the two line of research stay well separated perhaps helped by the fact that their object of study was coined differently (behavioral matching versus interpersonal synchrony). However, an open question is to which extent these two concepts refer to the same underlying mechanisms.

Another research topic which fosters much more theoretical debates is joint action. A joint action can be defined as "*any form of social interaction whereby two or more individuals coordinate their action in space and time to bring about a change in the environment*" (Sebanz, Bekkering, and Knoblich 2006). This object of research is different from behavior matching and interpersonal synchrony in two aspects. Firstly, joint actions are intended which bring in the debate the questions of goals, intersubjectivity, etc. Secondly, typical studied tasks are more complex to approach real life situations : "*Researchers are just beginning to acknowledge that to reach a more comprehensive understanding of the processes underlying social interaction, one needs to move on from studying the processing of social stimuli towards investigating real-time social interactions*" (Sebanz, Bekkering, and Knoblich 2006). Joint action tasks, alternatively labelled cooperative tasks, are not new: tasks such as two-person card sorting task (C, O'Brien, and Sysko 1999) or solving a puzzle task (Shockley, Santana, and Fowler 2003) can be considered as joint actions. But the recent formulation of this object of research fostered the investigation of various cooperative tasks engaging the partners' bodies. Because it engages a complex interplay of behaviors, reviews about the topic propose to structure the object in sub-components. In their reviews, (Sebanz, Bekkering, and Knoblich 2006) (Sebanz and Knoblich 2009) identify three necessary abilities for the succeeding of joint action: sharing of representation through joint attention, the prediction of actions thanks to the perception-behavior link and to integrate predicted effects of own and others' actions to achieve coordination. Similarly, (Keller, Novembre, and Hove 2014) proposed a theoretical framework where coordination require to develop cognitive-motor skills ("*real time skills*") in anticipation, adaptation and attention. They add to this decomposition four moderators: the individual goal, the knowledge about the task and the partner, the use of regulatory strategies to facilitate coordination and socio-psychological factors such as personality traits. Within these frameworks, behavior matching and interpersonal synchrony are related to the only component of mutual adaptation.

The main contribution of the concept of joint action for this thesis is a theoretical one. The study of joint action is an attempt to explain human cooperation from low level mechanisms of coordination: a kind of "*embodied cooperation*" hypothesis (Marsh, Richardson, and Schmidt 2009a). Traditionally, in a cognitivist view of social cognition, cooperation is explained via exchange theory and experimental paradigms such as the prisoner dilemma (Baron 2007). However this disembodied perspective is a very special case omitting critical aspects of cooperation "*involving self-organized emergence of joint actions designed to create mutually beneficial outcomes*" (Baron 2007). Whether it is from the representational perspective of mirror neurons (Sebanz, Bekkering, and Knoblich 2006) or the dynamical approach (Marsh, Richardson, and Schmidt 2009a) (Shockley, Richardson, and Dale 2009), authors from

various approaches debate about the nature of the complex cooperation patterns emerging from tasks involving real-time interactions (Figure 17).

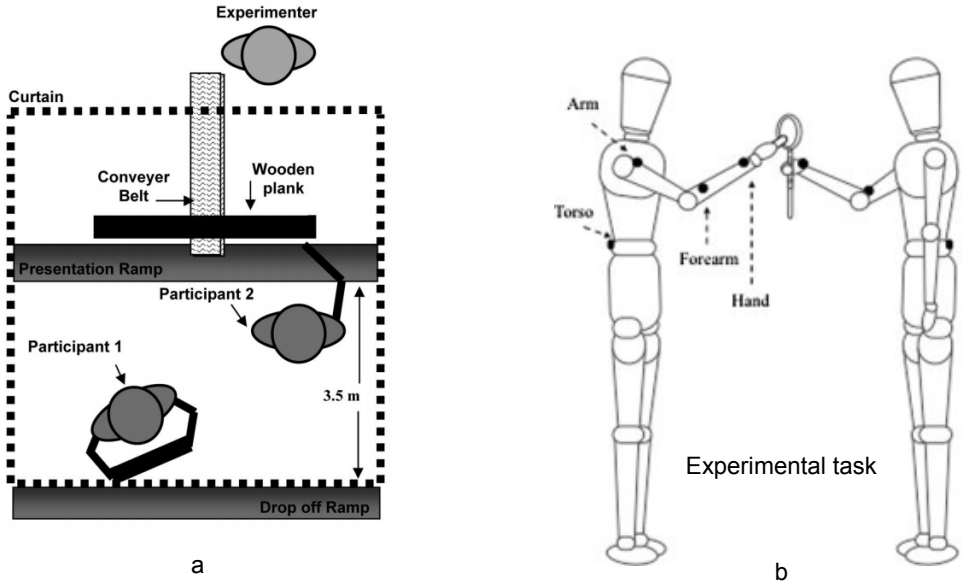


Figure 17: a) (M. J. Richardson, Marsh, and Baron 2007) b) (Ramenzoni et al. 2012)

From these articles, a somehow clear dissymmetry appears in the account for joint actions and social cognition. The representational account of ideomotor theories (Shin, Proctor, and J 2010) is more at ease in issues related to the individual alone (e.g. the control of mimicry in social interaction (Y. Wang and Hamilton 2012)) with still unsolved issues on the mutual aspect of interaction: the motor resonance explanation from mirror neurons is not so straightforward (Frédérique de Vignemont 2014). On the other side, the dynamical perspective which appeared limited to a very restrictive number of tasks adopted new concepts which enlarge its perspectives: interpersonal synergies – "*higher-order control systems formed by coupling movement system degrees of freedom of two (or more) actors*" – from motor control (Riley et al. 2011), coordinative structure – "*a self-organized, softly assembled (i.e., temporary) set of components that behave as a single functional unit*" – (Shockley, Richardson, and Dale 2009) and affordances from ecological psychology – "*opportunities for actions*" – (Marsh, Richardson, and Schmidt 2009b) enable to draw hypotheses in more complex coordinative tasks. In addition to this opening, a convergence from various emerging hypothesis approaches to the "*social interaction*" issue (always in the application case of joint action) is currently generating an effervescence in theoretical propositions (Froese and Gallagher 2012)(Kyselo and Tschacher 2014)(Laroche, Berardi, and Brangier 2014)(Dumas, Laroche, and Lehmann 2014)(Fantasia, De Jaegher, and Fasulo 2014)(McGann 2014). A recurrent attempt is to propose to articulate a dynamical perspective of coupling based on an enactivist view of cognition and a phenomenological approach helping to grasp the key nature of intersubjectivity (Ickes et al. 1988). Interestingly, this theoretical proposition goes beyond bodily coordination in joint activities to reach other processes such as the study of dialogue (Garrod and Pickering 2009)(Fusaroli, Rączaszek-Leonardi, and Tylén 2014)(Fusaroli, Gangopadhyay, and Tylén 2014)(G. J. Mills 2014). A current theoretical debate is about how to articulate the individual and the interactive domain (Dumas, Kelso, and Nadel 2014). Although going in the detail of these freshly emerging theories is beyond the scope of this PhD thesis, we cannot avoid to be influenced by the definition of autonomy as relational in enaction: "*living has been defined as the self-production and self-maintenance of its own organization, […]. It is thus a network whose operations are closed (i.e., each process has causes in and effects on other processes of the system). This interdependency enables the self-organized emergence of a coherent living unit. […]. By producing itself, the living system actively "affirms" its own identity (it specifies what it is), and thereby defines its own intrinsic laws or norms of self-maintenance. In a word, the living system is auto-nomous (Varela, 1979; Di Paolo, 2005; Barandiaran and Egbert, 2014). However, the*

autonomy of the living system is bounded by the domain of its viable relations with the environment. The boundaries of the living are therefore relational (rather than merely "skin-bounded")" (Laroche, Berardi, and Brangier 2014). The second key aspects of this vague of propositions relevant for this thesis is the consideration that interpersonal interaction play a constitutive role in the emergence of social cognition. This view is in total opposition with traditional descriptions of social cognition in terms of individual abilities of mind reading (Theory of Mind). This important shift has been coined the interactive turn.

2.1.5. The interactive turn and its methodological implications

A cognitivist account of cognition considers the "*mind/brain as an organ for building internal representations of external world. By performing internal computation over these representations, the mind/brain comes to a decision about what actions are appropriate.*" (Marsh, Richardson, and Schmidt 2009). This dominant paradigm enabled to deepen the understanding of the individual psyche but narrowed significantly the study of social phenomena: "*relatively few researchers in the area of social cognition have bothered to inquire how the contents and processes of one mind are related to those of another. Instead, using as their models the studies conducted in more traditional areas of psychology, they have inquired how the contents and processes of individual minds tested "one at a time" are related to "social" stimulus materials whose features and contents have been predetermined by the experimenter. In consequence, the field of social cognition is currently one whose "preoccupation with social information processing" (Swann, 1984, p. 458) has cast the social perceiver in the role of "a hermit, isolated from the social environment," and has relegated other people to the status of experimental "stimuli" or perceptual "targets'*" (Ickes et al. 1988). This experimental approach to social phenomena has been coined "*methodological individualism*" (Lenay and Stewart 2012)(Froese and Gallagher 2012).

Whether or not a researcher adheres to an enactivist view of cognition, this methodological question is of particular importance when dealing with the study of social phenomena. As said by (De Jaegher, Di Paolo, and Gallagher 2010) "*the current understanding of the role of social interaction in social cognition is limited*", and the few available studies analyzing at a fine grain the evolving pattern of mutual adjustments provide promising results regarding some pillar notions of social cognition. For example, (Lenay and Stewart 2012) used a minimalist experimental protocol of perceptual substitution to reveal the strategies used by partners to identify each other's. Basically, it is the crossing of the two perceptions which enabled each other to detect the other, a collective effect which could not have been evidence in a methodological individualism. In addition, they further investigated these patterns and evidenced the emergence of mirror-resemblance (Lenay and Stewart 2012). Spontaneous behavior matching could be a consequence of the interactive dance between two individuals, as stated in (Dumas, Kelso, and Nadel 2014): "*the disposition of human and monkey to imitate is not due to a passive coupling of perception and action. Rather it is an active attempt to adapt and gradually refine their own movements with respect to others*". This analysis was confirmed using evolutionary robotics methods (Froese, Lenay, and Ikegami 2012) and replication was published in the Nature journal (Froese, Iizuka, and Ikegami 2014).

The methodological implication of these elements is that a truly social experiment paradigm should preserve the autonomy of the social interaction: "*it is crucial that experimental designs do not prevent engagement from developing*" (De Jaegher, Di Paolo, and Gallagher 2010). The first approach which exists is the collection of behaviors in natural settings with the use of non-pervasive material such as cameras (E. O. & Grammer and Karl 2008). It is important to note the essential difference with experimental setup where one of the dyad members is a confederate acting a special experimental condition such as mimicking on purpose (Chartrand and Bargh 1999a): in such a case the spontaneous engagement is broken. The main limitation of a more naturalistic approach is the lack of control over the interactions which are complex in nature. The second approach propose to deal with the issue of controllability by setting up mediated interactions where both partner can still engage in an online interaction but

through a minimalist communication channel. Figure 18 shows two different experimental paradigms: the perceptual crossing setup of (Lenay and Stewart 2012) and the human dynamic clamp from (Dumas et al. 2014). As early protocols of dynamical systems approach to interpersonal synchrony, these setups are designed to capture the essence of the interactive phenomenon but are hardly generalizing to everyday situations. It is interesting to note that some proponents of the behavioral matching line of research also discussed the issue of controllability, but without considering the problem of methodological individualism. For example, (Y. Wang and Hamilton 2012) proposed a minimalist in the form of "*novel social stimulus-response compatibility paradigm*". Without true interaction, this paradigm fall into the critical description of social cognition paradigm made by (Ickes et al. 1988).

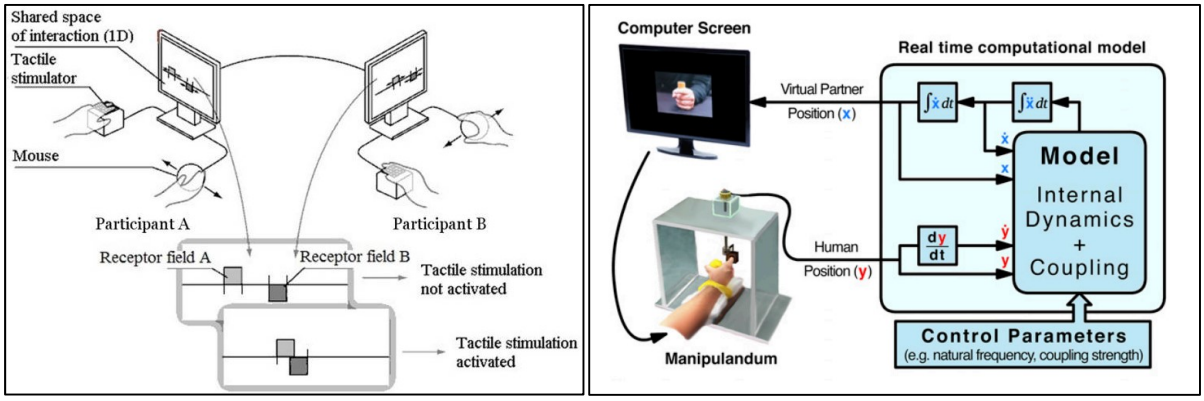


Figure 18: two minimalist interactive protocols (Lenay and Stewart 2012) (Dumas et al. 2014)

The last "*promising route*" (De Jaegher, Di Paolo, and Gallagher 2010) is the use of virtual characters with "*truly interactive paradgims*" (Wilms et al. 2010). For example, (Wilms et al. 2010) present an experimental setup for an imaging study where the gaze of the virtual human establish "*online reciprocity*", with the interactive animation of gaze based on collected data. This last option is of primary importance for the purpose of this PhD thesis because it demonstrates the essential role of interactive virtual humans based on real-life data as a future paradigm for the study of social cognition. Given the development of data-driven approaches highlighted in the section on Computer Sciences, and their need to be informed by sound theoretical grounds, including in IVA development the objective of possibly being used as experimental tools for Human Sciences could constrain positively the development of interactive applications.

2.1.6. Conclusions

This review provided a review of behavioral matching and interactional synchrony processes, the two identified spontaneous low level interactive phenomena. This literature seems to move toward a more general use of the concept of synchrony which could encompass the phenomenon of mimicry and is more dynamic in nature. Given the increasingly importance of movement at the origin of perception, it appears coherent that social interaction are continuous and mutually adaptive (E. O. & Grammer and Karl 2008). Also, the construct of synchrony is currently generating a tremendous amount of theoretical proposition in order to explain intersubjectivity and social cognition. For this reason, grounding future full body interaction works in HCI on this framework seems the best alternative. An additional reason is that, for the research object of social interaction, Human Sciences and Computer Sciences are complementary in their approaches and need reciprocal developments. Moving on this interdisciplinary ground promises fruitful collaborations and deeper understanding of the human sociality.

Another outcome of this review is the fact that interpersonal processes are highly flexible: they depend on individual dispositions and contexts. From the review, we got some indications about individual differences influencing these

interpersonal processes. If we take together the results from behavioral matching and interactional synchrony, the list of individual differences is not so long:

- Perspective taking (Interpersonal Sensitivity Index)
- Self independence / interdependence (Self Construal Scale)
- Pro social versus pro self orientation
- Field dependence / independence (cognitive style measured via the EFT)
- High versus low self-monitoring

A remarkably absent individual difference from this short list is the Five Factor of personality. Although it is the only theory used in Computer Sciences, no Human Sciences researcher chose it as an independent variable. This does not mean that any of the Five Factor traits are not relevant, but other assumptions and variables appeared more coherent. Another limitation of this literature is the study of the magnitude of coordination only between individuals. Most of the studies investigate the absence or presence of coordination and explore possible moderator variables. Very few studies propose hypotheses about the pattern of synchronization, for example about the lag of reactions (Hart et al. 2014).

To understand in more details the reason why the identified individual differences are relevant, identify other potentially interesting dispositional variables and attempt to build hypotheses about possible patterns of social interactions, we continue our review of the literature in Human Sciences by focusing on three objects: empathy processes (and related dispositions, such as perspective taking), dispositions related to pro-social orientation and social bonding (such as interdependent self) and cognitive style (more specifically Field Independence / Dependence (FID)). This last point – the study of Field Independence / Dependence, a cognitive style – is a particularly promising route for the understanding of individual differences in social interactions: cognitive styles were originally conceptualized as a possible bridge between personality and the way individuals process visual and proprioceptive cues to perceive their environment. We also discuss the articulation with the Five Factor model in order to provide a bridge with the existing literature in Computer Sciences.

2.2. Empathy and self-other merging

"*Empathy can perhaps be considered as the most "social" of phenomena because it can only arise within some kind of interpersonal context*" (Tiedens and Leach 2004). Since four decades, empathy has been an active research topic in human sciences, a result from its tight associations with helping, care and pro-social behaviors (Eisenberg, Eggum, and Di Giunta 2010). Although researchers agree upon the central role of empathy in interpersonal relationships, no consensus has been reached about the definition of empathy (Decety and Ickes 2011). Various terms – e.g., *empathy, sympathy, perspective taking* – are used to refer to sometimes similar and sometimes dissimilar constructs. In order to identify and understand individual differences related to empathy, we review here some of the most important definitions which enable us to decompose into various component the empathy concept. More particularly, definitions vary mainly along two dimensions/oppositions: the cognitive versus affective empathy oppositions and the process versus outcome definitions of empathy.

2.2.1. Early theories: empathic responses of sympathy and personal distress

Back in the eighties, empathy was rather define as an outcome (Gruen and Mendelsohn 1986), a reaction to the observed experiences of others and already included the affective and cognitive aspects of empathy: "*Empathy in its broadest sense refers to the reactions of one individual to the observed experiences of another. […] A cognitive, intellectual reaction on the one hand (an ability simply to understand the other person's perspective), and a more visceral, emotional reaction on the other.*" (M. H. Davis 1983). The cognitive aspect of empathy is understood as an

attempt to understand the subjective experience of another, to "*reach out*" for the other person, while the affective aspect is associated with the sharing of emotions, to be "*moved by*" another person in suffering (Wispé 1986).

Affective empathy is often interchangeably associated with sympathy as a "*heightened awareness of the suffering of another person as something to be alleviated.*" (Wispé 1986). Conceived as such, sympathy is an asymmetrical emotion response with concerns of the other well-being, it is an other-oriented response. Inversely, some authors conceive affective empathy as the symmetrical emotional reaction to others' affects, a definition similar to emotional contagion. "*Empathy as an emotional response entails [...] a matching of affect, between an observer and the person being observed. Sympathy, on the other hand, does not involve a reproduction of the emotion perceived in another but is, rather, a response of compassion or concern evoked by the plight of another*" (Gruen and Mendelsohn 1986). A slightly different view of emotional responses to another's affect is to consider the opposition between self-oriented versus other-oriented responses, namely personal distress and sympathy: "*Sympathy is defined as an other-oriented emotional reaction (such as concern) to another's emotional state or condition, whereas Personal Distress is defined as a self-oriented, aversive emotional reaction such as anxiety or discomfort*" (Eisenberg et al. 1989). This opposition in response orientation has been shown to be a particularly good predictor of prosocial behaviors, with distressed individuals helping only when escape from the situation is impossible, and with the underlying motivation of alleviating their own discomfort.

2.2.2. Empathy as a process

The consideration of empathy as a process (underlying the responses) rather than an emotional response enable to clarify the different concepts. The model proposed in (Eisenberg et al. 1994) is very interesting for three reasons. Empathy is considered as a process where personal distress and sympathy are different consequences. In addition, the empathic process, which is "*a vicarious emotional response that is identical or very similar to that of the other person*", is related to the emotional intensity of the other affect and can also occur as a consequence of cognitively taking the perspective of another. Thus, a mere cognitive understanding of the other experience without vicarious emotional response is not included in this vision of empathy. Finally, emotion regulation is added as a key component which modulate the affective response (Sympathy vs Personal Distress): "*it is reasonable to assume that empathic overarousal in negative contexts ([...]) is experienced as self-focused personal distress. If this is the case, individuals who are unable to maintain their emotional reactions within tolerable range ([...]) would be expected to be more likely than other people to experience personal distress, to focus on their own needs, and to behave in ways that do not necessarily facilitate positive interactions in emotional situations*" (Eisenberg et al. 1994). Well regulated people are able to modulate their negative emotional states which open the possibility to feel sympathy (Figure 19). Since, the view of sympathy and personal distress as two distinct empathic response has been confirmed, and evidence show that both can be experienced (Carrera et al. 2013). If this model articulate clearly the different component considered in the literature, it does not investigate the empathic process itself.

Figure 19: Theoretical model proposed in (Eisenberg et al. 1994)

(C. M. Davis 1990) propose to go more in details in the empathic process. They decompose the empathic process in three steps: first, individuals A and B are isolated and A comes to listen/observe B. Second, A feels deeply connected to B and a form of identification of A to B occurs. Third, A gets its "*self back*" to experience sympathy for B (Figure 20). Even if (C. M. Davis 1990) is not clear about the origins (perspective taking or emotional intensity) and the

emotional responses (sympathy versus personal distress), this view is interesting as it put the self-other merging of identities and experiences as the core of the empathic process.

Figure 20: Empathic process described in (C. M. Davis 1990)

Originally, the idea that selves representations can "*overlap*" comes from close relationships research (Aron, Aron, and Smollan 1992). In this perspective, people's sense of interpersonal connectedness is associated to the degree of overlap (number of shared positive attributes or self-other definition similarity). In the Inclusion of Other in the Self (IOS) scale, this overlap is literally assessed via overlapping circles (Figure 21). While the scale was intended to the study of close relationships, authors recognized the importance of the construct for empathy research, considering that "*empathy may stem in part from a basic confusion between ourselves and others*" (Aron, Aron, and Smollan 1992).

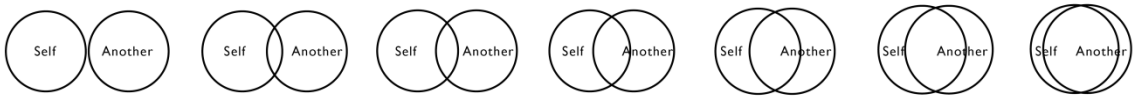


Figure 21: Other in the self scale (Aron, Aron, and Smollan 1992)

The idea of a self-other merging within the empathic process has been the subject of much debate. Some authors emphasize the importance of the degree of overlap between the selves in determining the prosocial response (degree of sympathy) (M. H. Davis et al. 1996). Conversely, Batson and colleagues argued that self-other distinctiveness is necessary to feel empathy: "*one must recognize the uniqueness of the other and his or her experience, distinct from oneself and one's own experience, to appreciate the plight of and the feel for another*" (Batson et al. 1997). This opposition is the result of a not clearly delineated definition of affective and cognitive empathy. Evidence are accumulated that the active process of perspective taking (i.e. the process of imagining the word from another's vantage point) leads to self-other overlap (Galinsky, Ku, and Wang 2005) (Laurent and Myers 2011) which in turn is associated with prosocial behaviors (Chartrand and Bargh 1999a). Thus, overlap as similarity between the selves' definitions is a consequence of cognitive empathy (understanding of other by perspective taking), but is not involved in affective empathy (vicarious emotional response to others' affects) which is more a sharing of emotional experience. Confusedly, a recent debate in the journal of Emotion Review defined self-other overlap as "*any phenomenon whereby an observer engages a state similar to that of the target via activation of the observer's personal representations for experiencing the observed state*" (Preston and Hofelich 2012). More precisely, self-other overlap is considered as a combination of neural overlap (from the ideomotor framework) and a subjective overlap (conscious resonance with the target). Defined as such, we see here a definition of the affective empathic process which is totally different from the overlap between selves' representations which can occur in active perspective taking (Eisenberg and Sulik 2012).

Recent advances in Neurosciences and Ethology provide new elements to understand the empathic process. (Decety and Jackson 2004) extensively explored empathy as a process and proposed three components: 1/ affective sharing between the self and other, based on perception-action coupling that lead to shared representations, 2/ self-other distinctiveness enabled by emotion regulation "*to keep track of self and other-feeling*", 3/ mental flexibility to take the perspective of others. As in (Eisenberg et al. 1994), regulation is considered as a moderator of the empathic

response: without regulation, the person response is personal distress (Decety and Ickes 2011). However, perspective taking is not a possible precursor of the empathic process but a parallel component.

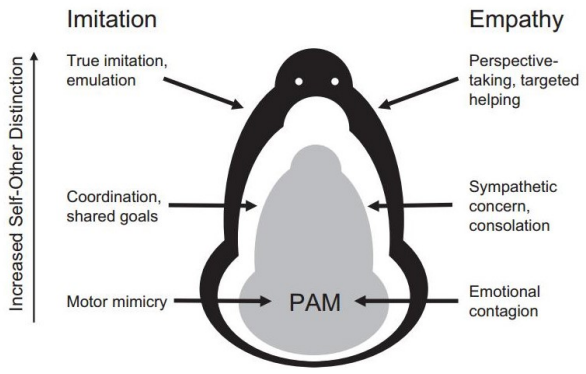


Figure 22: Phylogenetic model from (de Waal 2008)

This view is complementary to a phylogenetic model proposed by the etologist (de Waal 2008) (Figure 22). The first element of empathy shared across the animal kingdom is emotion contagion: "*The lowest common denominator of all empathic processes is that one party is affected by another's emotional or arousal state*". The second level of empathy is the possibility to feel concerns for the other (sympathy), which rely on a separation between internally and externally generated emotions. Finally, the third level of empathy and the more mature is empathic perspective taking.

"*Psychologists usually speak of empathy only when it involves perspective-taking. They emphasize understanding of the other, and adoption of the other's point of view. In this view, then, empathy is a cognitive affair dependent on imagination and mental state attribution, […]. Perspective-taking by itself is, of course, hardly empathy: It is so only in combination with emotional engagement.*" Again, at the heart of this evolution is the perception-action mechanisms (actions of the one activate the same representations of the action in the other). Also called the ideomotor framework of human actions, it enables the integration of theory convergences in model of imitation and empathy (Iacoboni 2009). This conception leads authors to propose a "*Russian doll*" model with a parallel development of empathy and imitation abilities (Figure 22).

Firstly assumed to be a mere motor resonance mechanism, modern theories of empathy highlight the flexibility of the process modulated by individual differences and context (Hess and Fischer 2013). A popular cognitivist account for this flexibility is to consider empathy resulting from an appraisal process, either coming early or late in the empathic process, as in Figure 23 (Frederique de Vignemont and Singer 2006).

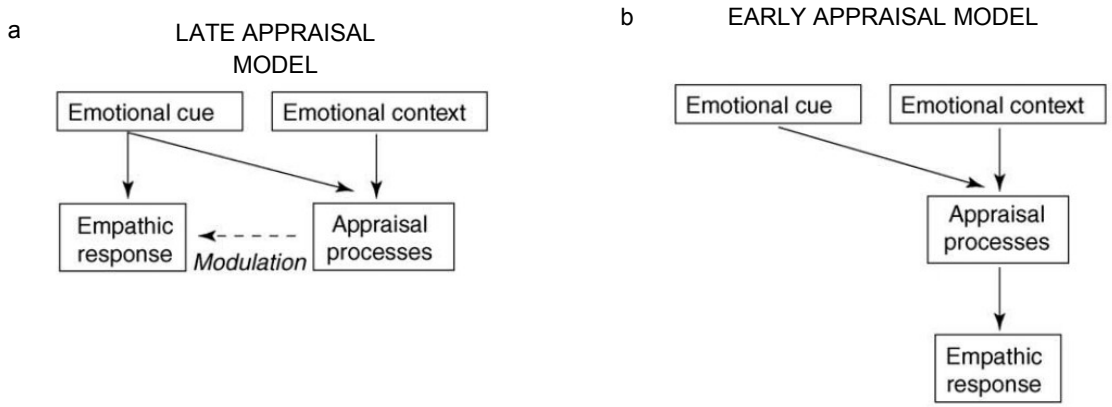


Figure 23: Late and early appraisal processes (Frederique de Vignemont and Singer 2006)

2.2.3. Empathic motivations

A last important aspect of empathy is the motivation behind prosocial behaviors. Considering an individual with good emotion regulation abilities in an empathic situation, he would manage to keep low his personal distress and

limit self-oriented aversive emotions. However, this regulation ability alone cannot explain the other-oriented sympathy feeling which is associated with "*an approach orientation towards other in needs*" (Niezink et al. 2012). The study of compassion is an interesting topic providing insightful elements about this issue. Sympathy and compassion are very close feelings, often associated with warmth, kindness and caring (Goetz, Keltner, and Simon-Thomas 2010). (Singer and Klimecki 2014) put compassion in opposition to empathic distress, assimilating compassion to empathic concern and sympathy: "*While empathy refers to our general capacity to resonate with others' emotional states irrespective of their valence — positive or negative — empathic distress refers to a strong aversive and self-oriented response to the suffering of others, accompanied by the desire to withdraw from a situation in order to protect oneself from excessive negative feelings. Compassion, on the other hand, is conceived as a feeling of concern for another person's suffering which is accompanied by the motivation to help. By consequence, it is associated with approach and pro-social motivation*" (Figure 24).

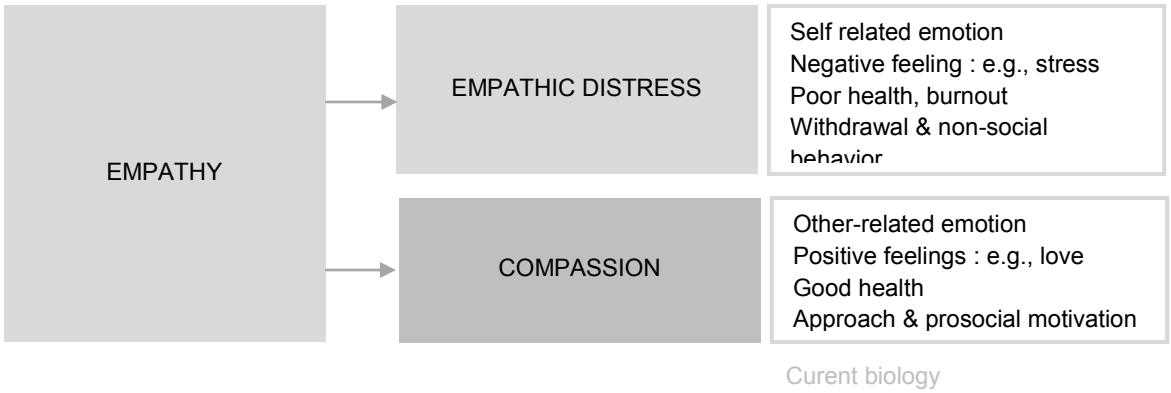


Figure 24: Paths of empathic distress and compassion (Singer and Klimecki 2014)

At an evolutionary level, compassion related feelings evolve as a distinct response because it is essential for the welfare of vulnerable offspring and it enables cooperative relations with non-kin (Goetz, Keltner, and Simon-Thomas 2010)(Waal 2012). If this other-orientation is considered to be present in every human, variation according to states and traits exist which might modulate the sympathy responses. This is where individual differences in pro-social orientation (such as self-interdependence) might come at play. Confirming this line of research, (Zaki 2014) proposed in a very recent synthesis to ground our understanding of empathy in motivation and self-regulation strategies: "*interdisciplinary evidence highlights the motivated nature of empathy, and a motivated model holds wide-ranging implications for basic theory, models of psychiatric illness, and intervention efforts to maximize empathy*".

Together this literature provides a big picture about the different component underlying the empathy concept. As no consensus exists, we take as a base the model proposed by (Eisenberg et al. 1994) with some adaptations to include recent theorization of the empathic processes (Decety and Ickes 2011) as swhon in Figure 25. Perspective taking, considered as the core of cognitive empathy, can lead to empathic concern without necessary vicarious feelings (affective empathy): the two processes are parallel. In our representation, we also make explicit the influence of the prosocial orientation moderation on the empathic concern response: depending on states and dispositions, an individual will be more or less inclined to feel concern for others. Finally, we make clear the distinction between self-other affective awareness – tightly related to emotion regulation which enable to differentiate other-versus-self emotions – and self-other attributes overlap – tightly related to prosocial orientation but also to concepts such as similarity and familiarity (Tan et al. 2015) –. This model is conceptual, provides working hypotheses and is based on a literature using multiple different methods, from experimentally controlled setup to daily interaction reports. For easy referencing, we will refer to this model as HIDID – Hypotheses about Individual Differences in the Interpersonal Domain –. In the following, individual differences related to empathy are reviewed with interpretations

made accordingly the proposed model, and the few studies investigating empathy at the dyadic interactional level are reviewed.

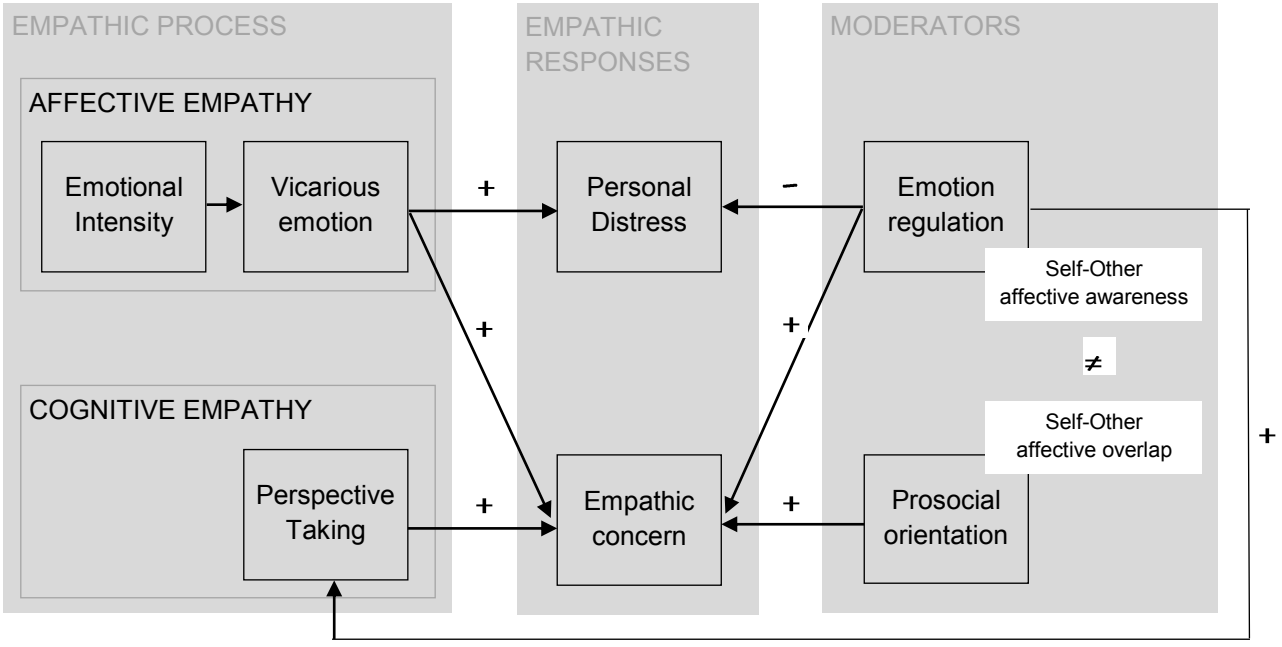


Figure 25: Summarizing hypotheses linking of empathic processes, responses and moderators in the HIDID model

2.2.4. Individual differences in empathy and emotion regulation

Individual differences related to the different component of empathy have been investigated by means of various self-report measures (Gohm and Clore 2000). Several measures adopted a unidimensional approach leading to a too narrow definition of empathy, necessarily focus on only one aspect of empathy (cognitive or affective). Conversely, (M. H. Davis 1983) proposed a multidimensional view of individual differences in empathy which includes various component similar to the elements identified in our previous review. The resulting Interpersonal Sensitivity Index (IRI) is the most widely used questionnaire in the field. It includes four dimensions: Empathic Concern (EC), Personal Distress (PD), Perspective Taking (PT), and Fantasy (F). The empathic concern scale assesses the extent to which the individual have other oriented feelings of sympathy, the personal distress scale assesses the extent to which the individual have self-oriented feelings of personal anxiety in tense interpersonal settings, the perspective taking scale assesses the extent to which the individual have the capacity to have non-egocentric though, and the fantasy scale assesses the extent to which the individual have the capacity to identify with an imaginary character. EC, PD and PT correspond exactly to their respective component in the proposed model, with only F being difficult to position. Investigating the latent structure of the IRI, (Pulos, Elison, and Lennon 2004) identified two higher order factors separating PD on one side and EC, PT and FS on the other side. Authors argued that the PD factor was related to emotion control (regulation) and coined the second factor "*general empathy*". Some authors proposed measures of sympathy alone as in (Lee 2009). Consistently, these studies find close relationship between the built sympathy scale and the empathic concern scale from the IRI. More recently, (Lietz et al. 2011) built a new multidimensional self-report tool for the assessment of empathy resulting in a five factor structure: affective response (corresponding to PD), empathic attitude (corresponding to EC), perspective taking (corresponding to PT), self-other awareness and emotion regulation. The two additional factors are interesting as they tape a missing component of the IRI (emotion regulation). Additionally, the high correlation between self-awareness and emotion regulation confirm the idea that both aspect might assimilated as one component, and that emotion regulation help to keep track of one's emotions.

Often developed independently from empathic questioning, tools to assess individual differences in emotion regulation are available (Calkins 1994). Emotion regulation is often defined as the ability "*to manage emotion arousal so that successful interpersonal functioning is possible*". One important aspect at the origin of emotion regulation is the ability to identify and discriminate the emotional experience: having a well differentiated emotion experience enables the individual to have more specialized and adaptive coping strategies (Barrett et al. 2001) (Swart, Kortekaas, and Aleman 2009). Alexithymia tapes exactly this phenomenon: it means "*no words for emotions*" and refers to the disability to identify and describe the affective experience (Parker, Taylor, and Bagby 1998). It is often considered to comprise two general deficits: reduced affective awareness and an externally orienting thinking. The Toronto Alexithymia Scale (TAS20) is by far the most widely used assessment scale (Bagby, Parker, and Taylor 1994). The questionnaires comprises of a three-factor structure, factors labelled Difficulties in Identifying Feelings (DIF), Difficulties in Describing Feelings to others (DDF), and Externally Oriented Thinking (EOT). The DIF and DDF are suggested to reflect affect-related alexithymia, whilst EOT is rather cognition-related (Grynberg et al. 2010). Alexithymia has been found to be related to emotional intelligence (Parker, Taylor, and Bagby 2001). Although Alexithymia has been theorized at the individual level, its associations to the interpersonal domain are considered as a maladaptive interpersonal functioning (cold/distant social functioning) (Vanheule et al. 2007). Recently, the associations between the subscales of the TAS20 and the IRI have been explored via factor analysis (Grynberg et al. 2010). As expected from the literature, IRI PD was associated with the emotion awareness scales from the TAS20 (DIF and DDF), all the other scales loading on another factor coined "*cognitive*". Within a public speaking induced social stress paradigm, (Pollatos et al. 2011) found that DDF was the scale the most strongly associated with emotion regulation (reflected by a coherence between subjective feelings and sympathetic activations). Other approaches to emotion regulation focus on discriminating various and preferred way to cope with emotion arousal, such as suppression or attentional deployment (Webb, Miles, and Sheeran 2012), but their more cognitive way to approach emotion regulation appear out of the scope of this PhD thesis.

These various explorations of the correlates and factorial structures of the two most widely used questionnaires for empathy and emotion regulation self-report comfort the proposed integrative model. Rather than considering the interpersonal domain with empathic processes on one side, and the intrapersonal domain with self-regulatory processes on the other, the combination of both may provide a more comprehensive view of interpersonal outcomes/behaviors.

2.2.5. Empathy in nonverbal emotional interaction and individual differences

Almost unanimously, the literature on empathy is based on stimulus-responses experimental paradigms. For example, individuals are presented to facial emotional expression in photos and facial reactions (by means of electromyography), cerebral activation and subjective feelings are assessed (Wild, Erb, and Bartels 2001). Following this paradigm, the study of emotion contagion in bodies have been studied with photo of bodily emotion expression as stimulus (Gelder et al. 2004) and recently a methodology have been proposed to measure the muscular activations of the upper body while watching emotional stimulus. This total reliance on individualist methodologies have been criticized by researchers from the field: "*whereas research on postural mimicry has often been conducted in interactive settings (e.g.,(Chartrand and Bargh 1999)), research on facial mimicry has generally employed settings of limited sociality by using photos, videos, or computer-generated avatars*" (Hess and Bourgeois 2010); "*When people experience and express emotions in real life, they are often in social setting communicating in real-time dynamic interactions with responsive individuals expressing subtle and ambiguous emotions about complex situations. When participants experience and express emotions in the laboratory, they are often in a socially isolated setting confronted with simple emotional stimuli such as still photo. Interaction partners are often represented in the form of static photographs or non-interactive videotapes of others' expressions. Usually, these bogus interaction patterns display*

strong and unambiguous emotions toward unspecified objects. High level of experimental control are therefore traded for high level of artificiality" (Bruder et al. 2012).

An alternative method have been to rely on affect self-report of dyad members over long time period with roommates or husband-wife dyads (Ferrer and Nesselroade 2003) (Anderson, Keltner, and John 2003)(Parkinson and Simons 2009). While being really dyadic in nature, these studies provide no information about the empathic process at the social interaction level. To our knowledge, only two recent studies propose an investigation of empathy in a truly social interaction. (Hess and Bourgeois 2010) provided "*the first to show evidence for facial mimicry in an interactional setting*". They asked one member of a dyad to relate an angry or happy event from their life to the other dyad member and measured facial mimicry via electromyography and noted facial mimicry occurring for Duchenne smiles. The second study is from (Bruder et al. 2012) and designed a co-watching film paradigm: dyad members jointly watched a movie eliciting an emotion in two conditions: with and without seeing each other. They varied the types of dyads (friends and strangers), types of emotions (amusement, fear and sadness) and component of emotions (facial expressions, cognitive appraisals and subjective feelings). They evidenced social facilitation of emotion (the intensity of emotion changes when other people are present) and emotional convergence (the emotional response of interactive individuals tend to be congruent) with varying pattern as a function of the study independent variables. These two studies show that it is possible to study empathy in an interactive context, but provide us no information about empathy in bodily interaction and related individual differences.

Regarding individual differences in empathic responding, the self-report questionnaire of traits empathy is the main tool investigated with empathic individuals mimicking more (Sonnby–Borgström 2002) and exhibiting more neural resonance when observing another's pain (Singer et al. 2004). (Avenanti et al. 2009) propose to investigate the different contribution of self-oriented (Personal Distress), other-oriented (Empathic Concern) empathic traits and cognitive empathy (Perspective Taking): they evidenced that Perspective Taking was associated with greater somatomotor response to others' pain whereas Personal Distress showed the opposite association. Reviewing findings from two different domain – the perception of pain and the vicarious touch activations –, (Bufalari and Ionta 2013) conclude that only empathy trait has been investigated. In both field, Perspective Taking have been found to foster empathic reactions. Empathic Concern and Personal Distress were positively and negatively related to empathic reactions in the pain observation literature only. Authors explain this difference by the inherent affective component of pain observation.

For emotion regulation, Alexithymia have been associated with reduced perceptual abilities in the observation of emotional expressions (Grynberg et al. 2012) and (Ihme et al. 2014) discovered that more alexithymic individuals take more time to label negative emotions (not positive emotions) of facial expressions. Previous studies only highlighted the lack of accuracy induced by alexithymia, but this paper revealed that by giving more time to label the emotion, it is time rather than accuracy that is influenced. We did not find any paper reported findings linking emotion regulation to empathic processes. Another line of research brings some interesting insight about the role of emotion regulation in motor control: (Bresin, Fetterman, and Robinson 2012) revealed in two studies how better emotion regulation is associated with higher motor control accuracy. The experimental paradigm is to ask participant to hold a joystick as accurately as possible on a presented visual target while hostile or non hostile thoughts are primed. Relevant to this PhD thesis, agreeableness trait of the Five Factor model was associated with more control accuracy, authors arguing that the emotion regulation component of this trait was responsible for this effect. (Beatty et al. 2014) employed a ballistic pinch grip paradigm (participants face visual emotional stimuli and "*upon stimulus offset, participants produced a targeted pinch force aimed at 10% of their maximum voluntary contraction*"). Measuring reaction time, rate of force production and performance accuracy, they evidenced that the pattern of reaction varied across different emotional regulation strategies, and authors to conclude "*findings provide evidence that emotion regulation strategies uniquely influence human movement*".

2.2.6. Conclusion

This review enabled us to clarify the various terms used in the empathy literature. Modern studies from various fields helped to disambiguate different but related phenomena such as emotion regulation, personal distress and compassion. We proposed a generic model articulating them and identified self-report questionnaires taping some of the useful constructs. The essential role of motivation toward an interpersonal orientation in fostering empathic responding has been highlighted recently. Thus, our next section will review individual differences related to this orientation, which is also in line with the conclusion of the section on interpersonal processes. Some uncertainty still remains in the presented literature such as the exact position of perspective taking in the overall model. Sometimes purely cognitive sometimes requiring to be emotionally engaged, another unclear aspect is the necessity of the motivation to affiliate to conduct the process of perspective taking. As perspective taking has been found to modulate spontaneous behavior matching, the investigation of these questions is of primary importance. Another unclear point is to whether it is more appropriate to consider emotion regulation as a low level unidimensional construct (here associated to Alexithymia) or to consider it at a strategic level to be closely related to coping strategies. For the purpose of this PhD thesis, we will stick on the first approach.

A major limitation of this literature is the unanimous reliance on methodologically individualist experimental paradigm to investigate the empathic process. In our review, we found only two papers proposing a truly interactive paradigm different from classical stimulus-responses studies. One possible reason for the hegemony of individualist paradigms is the current conceptualizations of emotion which stay mainly discrete in nature, related to discrete events. In this view, the empathy process can only be studied as a response, a reaction to a punctual emotion arising in another person. Only very recent theorization take seriously the circular causality between bodies and emotions, and more specifically between motion and emotion moving toward a more continuous and interactive view of affect (Fuchs and Koch 2014). Another more practical reason for this experimental limitation is the extensive use of intrusive sensors such as electromyography and electroencephalography which require the individual to be passive. Lastly, eliciting emotions in dyads remains a methodological challenge, partially answered with protocols such as in (Hess and Bourgeois 2010) and (Bruder et al. 2012). This overall limitation makes it hard to integrate findings in the empathy field and findings from interpersonal processes, even if influential empathy theorists have highlighted the proximity of these low level social phenomena (Waal 2012).

Although findings from this area are not coming from social interaction studies, the review of the influential individual differences in empathy provides some insight for the following of this thesis. Mostly studying individual differences in empathy, researchers revealed the different impacts of the sub-traits: perspective taking seems to foster interpersonal reactions across situation but empathic concern and personal distress come into play only in affective situation (e.g., painful situations). In such a case, they have an opposite effect: empathic concern foster reactions and personal distress inhibit them. Weak emotion regulation has been identified to impair the perception of emotional expression both in reaction time and accuracy. Also, it has been related to impair motor control under emotional event. Together, these findings provide initial evidence for the key role of emotional regulation in the embodied affective interpersonal processes. However, precise predictions of its effect cannot be drawn given the youthfulness of this investigation of emotion regulation in the interpersonal domain and the variety of conceptualization.

2.3. Self and social bonding

The section on interpersonal processes presented a detailed description of low level mechanisms occurring in social interaction (behavior matching and synchrony) as well as associated individual differences. Among them, the presence of empathy related variables leaded us to go in more detail in the process of empathy. From this second

literature review, we were able to delineate the various components of empathy and better understand the various individual differences involved in empathy.

The second type of individual difference highlighted in the first section is about differences in the pro-social orientation (self versus other oriented). These kind of individual differences are inherently based on differences in motivations: a pro-social value oriented person is assumed to have a heighted motivation to affiliate with others. As motivation has been defined as "*a state with potential energy, a force within the individual which is directed toward some goal*" (Graziano et al. 2007), an individual difference explicitly incorporating a motivation component provides an explanation of why specific behaviors arise in specific situations. Thus, it seems not surprising that researchers in interpersonal processes chose to use individual differences with interpersonal motivation components.

Because this difference in the nature of personality trait is of primary importance in the attempt to link personality to behaviors in context (e.g., synchrony in social interactions), we first discuss in more details the difference between the general descriptive nature of the Five Factor Model of personality (FFM) and more process oriented theories. Secondly, we introduce interpersonal theories of personality which most directly consider the individual identity as made by social phenomena. Thirdly, we show and review the similarities between various theoretical frameworks highlighting the soundness of a framework based on interpersonal theories of personality. Finally, specific issues such as the definition of autonomy, the place of emotion regulation and a re-conceptualization of some FFM traits are discussed.

2.3.1. Dynamics as the limit of the Five Factor model

The Five Factor Model of personality is derived from lexical analyses and has been shown to consistently and cross-culturally account for broad ways of behaving (Costa and McCrae 1992). Although this model is by far the most widely use framework of personality and have been shown to have good predictive validity in various situations, the approach is currently reaching a limit in the fact that "*individual's trait profile say nothing of the intraindividual relationship between the traits and how the traits interact with each other within an individual across time and situations*" (Aidan G. C. Wright 2011). Interestingly, this point was raised in an answer (A.G.C. Wright 2014) to the review of personality in Computer Sciences (Alessandro Vinciarelli and Mohammadi 2013) highlighting the sole use of the FFM.

The discussion of the limits of the normal trait-based approach (such as the FFM) and the description of the consideration of personality as a dynamic model in (Aidan G. C. Wright 2011) is very insightful to move on alternative description of individual differences. Among the different limitations proposed, three are important to consider:

- Pattern: "*Normal trait-based models do not (currently) contain a direct representation of processes and oscillation (or rigid lack of oscillation) between states*". This does not mean that the FFM traits do not account for some processes, but they have to be inferred a posteriori (detailed later in the section Five Factor model) by considering the additional findings in the literature
- Level: "*Personality exists at multiple levels of functioning that mutually influence each other (e.g., motivation, cognition, overt behavior, unconscious vs conscious). […] Overt behavior is given meaning by separating personality into its component processes and understanding functioning at multiple levels*". In a framework such as the FFM, no dissociations are made because no a priori theories are built. Authors take as an example the case of hostile aggression which are better explain when understood as a maladaptive strategy to satisfy the motivation for affiliation

- Specificity: "*Broad dimensions of normative functioning do not explain when and under what circumstances problematic functioning will occur. […] For example, narcissism predicts aggressive responses to ego threat, but psychopathy predicts aggression in response to physical threat*".

Overall, the essential argument is to move on from a general descriptive approach to an articulation of process based traits. Authors further describe this difference on the case of narcissism: "*Take, for example, the assertion that narcissists are "disagreeable extraverts". Although it might be the case that certain types of narcissism are associated with this trait profile, the reverse is not necessarily true, namely that all disagreeable extraverts are narcissistic. Arguably, what is unique about narcissism is the when, how, and for what purpose extraverted and disagreeable behaviors are enacted.*" These differences in the "way" traits are related to behaviors (by including the how, when and why) are better accounted by what authors call a dynamic model of personality based on "*an understanding of personality as an ensemble of structures and processes that include a self-concept, motivations, fears, and self-regulation strategies*".

The concept of a dynamics model of personality appear very promising as it highlights the interactive and variable nature of individual differences, and have the potential to explain pattern of interpersonal relations. Toward this direction, (Aidan G. C. Wright 2011) argue that interpersonal theories of personality are well suited to provide the ground of a more dynamical view of personality. As a future direction, including dynamics concepts to such models would enable to provide explanations for "*patterned enactment of behaviors*", such as: "moderation versus intensity (e.g., talking vs. shouting), flexibility versus rigidity (e.g., ability to shift behavior vs. repeating the same behavior over and over), stability versus oscillation (e.g., consistency within and across situations vs. unpredictable responses), and accuracy versus inaccuracy (i.e., the fit or match of behavior within a situation)."

Alternatively, some researcher propose to re-conceptualize the FFM framework in order to make it dynamic: by considering the density distribution of states as indicators of traits (Fleeson 2001), modeling interconnection between items and behaviors via neural networks (Cramer et al. 2012) or with the framework of cybernetics (DeYoung 2015). This critical description of the FFM clearly describes why the "*Big Five*" appeared so disembodied. Research in personality psychology is currently evolving toward such a more process based dynamic approach. For the purpose of this PhD thesis, it appears necessary to further investigate the interpersonal models of personality.

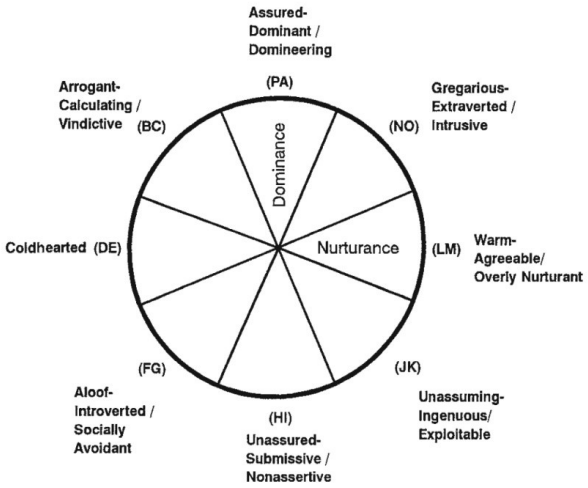
2.3.2. Interpersonal theory of personality

Although the origin of interpersonal theories of personality come from psychiatry (Sullivan 1953) (Leary 1957), developments in the last decades significantly enlarged the field of interpersonal theories. However, very few studies in the domain of social psychology consider these developments to account for individual differences in social interactions (Pincus and Ansell 2003).

The "*interpersonal*" dimension of this approach is not a narrow focus on individual differences occurring during social interaction, but rather the conceptualization of personality as emerging through interpersonal processes: "*interpersonal theory is not strictly an interaction theory emphasizing observable behavior; rather, the term interpersonal is meant to convey a sense of primacy, a set of fundamental phenomena important for personality development, structuralization, function, and pathology. It is not a geographic indicator of locale: it is not meant to generate a dichotomy between what is inside the person and what is outside the person. From a Sullivan stand-point, the intrapsychic is intrinsically interpersonal, derived from the registration and elaboration of interactions occurring in the interpersonal field*" (Pincus and Ansell 2003).

Across the various theories that emerged within this framework, a remarkable consistency appeared around the circumplex models, as it was for example evidenced in behaviors and language descriptions from (Wiggins 1979).

This circumplex model is a two dimensions model with affiliation (from hostile to friendly behaviors) and dominance (from submissive to dominating behaviors) as orthogonal axes (Figure 26).



Defining a 2D space, an individual can be placed wherever in the circle, the position defining the blending of the two axes and the distance to the origin the intensity. However, this conceptualization is not yet a structural model of personality: "*The interpersonal circomplex structure does not include specific structural or contextual references to the interacting other. Most often, it is used to describe qualities of the individual interacting with a "generalized other"*" (Pincus and Ansell 2003). Complementarily, some researcher took as the unit of analysis the dyad and proposed more structural models such as the Structural Analysis of Social Behavior (SASB) (Benjamin 1996) (Figure 27).

Figure 26: Circumplex model (Wiggins 1979)

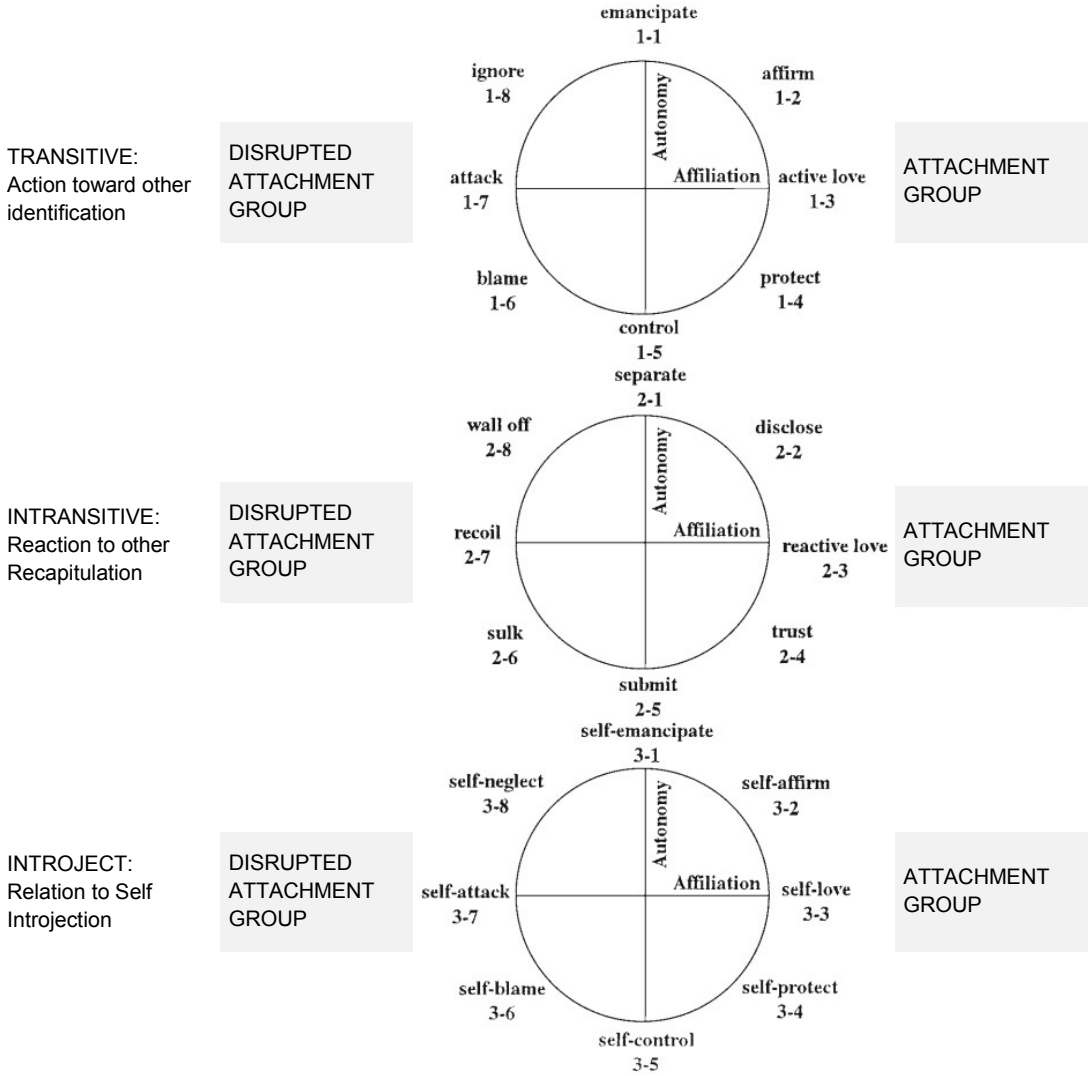


Figure 27: Structural Analysis of Social Behavior (SASB) (Benjamin 1996)

The advantage of this model is that it articulates the different level of the intra-psychic within the circumplex model of personality. For example, the dominance axis is renamed autonomy (less negatively connoted) and defined in terms of action toward others (high autonomy means tendency to emancipate), reaction to other (high autonomy means tendency to separate from others) and relation to self (high autonomy means tendency to emancipate the self).

Once these dispositions are identified, interpersonal theories of personality propose to define patterns of interpersonal adjustment. The classical cases are reciprocity for the affiliation dimension (more affiliation induces more affiliation of the other) and complementarity for autonomy (more autonomy induces less autonomy of the other) but are not reducible to these two: opposition, antithesis or introjections are also possible (Schacht 1994).

Going in more details in the structure of interpersonal personality theories to relate them to nonverbal interpersonal processes appears premature given the lack of articulation between this personality approach and social psychology. But the framework of the interpersonal circumplex model seems to be a parsimonious model to account for individual differences in the social sphere.

2.3.3. Two polarities models

What is remarkable with the two polarity model from interpersonal theory – two dimensional model including autonomy and affiliation as the primary axes to account for individual differences in the social word – is that various theorists from different domain recurrently proposed a similar structure. Calling them the "*two polarities*" model of human functioning (Luyten and Blatt 2013), (Luyten and Blatt 2011) reviewed some of them and conclude that "*although different theoretical labels are used in these various theories, there is remarkable theoretical as well as empirical overlap between these approaches*". These authors argued that taking into account this fundamental common structure would enable to integrate theory-driven and empirically-derived models of personality development. (Abele and Wojciszke 2007) even highlighted how judgment of others, judgment of the self, personality constructs, group perceptions and stereotypes can all be expressed in these two fundamental dimensions. This integration is a future promising approach which will need more time to develop. As a first approach, it appears important to acknowledge these different models.

Communion and Agency

Communion and agency have been proposed by (Bakan 1966) as the two "*fundamental modalities of human existence*". Communion underlying the fundamental motive for connection with one or more others and agency the fundamental motive for influence and mastery over the self (Gurtman 2009). Alternatively, (Abele and Wojciszke 2007) "*argue that agency is basically related to goal-pursuit of the self, and communion is basically related to considerations of others*" and (Diehl, Owen, and Youngblade 2004) described them this way: "*Agency refers to an individual's striving to master the environment, to assert the self, to experience competence, achievement, and power. In contrast, communion refers to a person's desire to closely relate to and cooperate and merge with others. Agency-oriented individuals experience fulfillment through their individual accomplishments and their sense of independence and separateness, whereas communion-oriented individuals experience fulfillment through their relationships with others and their sense of belonging*".

Self-Determination Theory

The Self Determination Theory (SDT) has been proposed as an approach to human motivation and personality "*that highlights the importance of humans' evolved inner resources for personality development and behavioral self-regulation*" (Ryan and Deci 2000). Within this framework, self-motivation and personality integration is organized

around innate basic needs that are essential for "*facilitating optimal functioning*". Three basic needs have been identified: competence, relatedness and autonomy. Competence refers to the experience of being effective in interaction with the social environment. Relatedness refers to the need to belong, caring for others. And autonomy refers to the experience of agency, "*being the perceived origin of one's own behavior*" (Deci and Ryan 2002). Thus, the SDT proposes two dimensions with an emphasis on the self and others respectively (autonomy and relatedness). Following the conceptualization of social bonding as a basic need (Baumeister and Leary 1995), the three needs defined in SDT do no vary in strength, but on "*the degree to which the needs have been satisfied versus thwarted*" (Deci and Ryan 2008). As a consequence, individual differences are explained by differences in self-determination autonomous, controlled and impersonal) and aspirations (or life goals).

Self-Construal

Cross-cultural psychology provides a similar picture of the motivated self. Based on the opposition between collectivist and individualist societies, (Hazel R. Markus and Kitayama 1991) proposed that individuals' self are shaped by their culture. Taking as a starting point the comparison between American and Japanese individuals, they described two different ways of relating with others. In individualist cultures, people have "*faith in the inherent separateness of distinct persons. The normative imperative of this culture is to become independent from others and to discover and express one's unique attributes*". In collectivist cultures, people "*insists on the fundamental connectedness of human beings to each other. The normative imperative of this culture is to maintain this interdependence among individuals*". They conceptualized two construals of the self: an independent self who view itself as a unique configuration of internal attributes, and behaves primarily as a consequence of these internal attributes; and an interdependent self who see itself as part of an encompassing social relationship and recognizing that one's behavior is determined and to a large extent organized by what the actor perceives to be thoughts, feelings, and actions of others in the relationship. If this early conceptualization propose a clear opposition between independence and interdependence near to a mono-dimensional model, later definition highlighted the independence of the two dimensions which vary in within cultural context (Singelis 1994) (Cross, Hardin, and Gercek-Swing 2010).

Attachment

Perhaps one of the most influential model is the attachment theory developed by (Bowlby 1969). It posits that humans have a universal need to form close social bonds and that the quality of early relationships between children and caregivers shapes future/adults social relations (Griffin and Bartholomew 1994). More specifically, four prototypic attachment patterns – secure, preoccupied, fearful and dismissive – are derived from a two dimensional model of adult attachment – avoidance and anxiety –. The anxiety dimension is inversely related to the positivity of the self: "*degree to which individuals have internalized a sense of their own self-worth and therefore expect others to respond to them positively*". When thoughts about the self are negative, the individual get anxious about others' feelings and develop a fear of rejection. The avoidance dimension is inversely related to the positivity of others: "*degree to which others are generally expected to be available and supportive*" (Griffin and Bartholomew 1994). When thoughts about others are negative, the individual avoids others and develop a discomfort with closeness. Each prototypical attachment style is related to patterns of interpersonal behaviors as well as affects regulation. The articulation between this developmental perspective and the communal-agency model has been described as such: "*The infant's attachment system keeps the child motivated to stay close and connected to the adult, an early manifestation of a communal motive that increases the child's chances of surviving infancy. Then, as children come to fell sufficiently secure about the caretaker's availability at times of need, they seek to separate from the caretaker and autonomously explore the environment. The motive to separate and explore is thus an early manifestation of an agentic motive*" (Horowitz et al. 2006).

Summary

These various interpersonal models from various research fields (e.g. psychodynamics, family therapy or cross-cultural psychology) provide insightful views on the origins, developments and outcomes of interpersonal motivation. Of particular importance is the remarkable convergence between these various approaches to interpersonal functioning: common to all are two independent dimensions – self-definition and relatedness – related to specific pattern of social functioning (Blatt 2008). "*In summary, there are similar two-dimensional conceptualizations of person attributes in social and personality psychology, which may be broadly subsumed under the headings like agency and communion. The agency dimensions relates to intellectual desirability, to competence, to initiating structure, to instrumentality, to egoistic bias, to dominance, and to an independent self-construal. The communion dimension relates to social desirability, to morality, to consideration, to expressiveness, to the moralistic bias, to nurturance, and to an interdependent self-construal*" (Abele and Wojciszke 2007).

What systematically differs between these approaches is the way to relate actual behaviors with the common dimensional structure. We found here the same challenge already stated in interpersonal theories of personality: provide structure and processes to account for human functioning. For the following, we consider the two dimensional model as a framework for individual differences.

2.3.4. Autonomy, emotion regulation and optimal functioning

Autonomy and Separation

Early works on two polarities models tended to oppose relatedness and autonomy, as for example in the Self-Construal Scale often took as a uni-dimensional scale with independence on one side and interdependence on the other side instead of a two dimensional plane (Singelis 1994) (Hmel and Pincus 2002). This was mainly due to a definition of independence near the concept of separation from studies on adolescence: independence is conceived as an interpersonal distance concept where the individual move away from the family to become separate, independent. This view places independence in opposition to connectedness with the family (Beyers et al. 2003). The more recent conceptualization of autonomy as agency enables to disambiguate this overlapping meanings (Kagitcibasi 2005) (Yeh, Bedford, and Yang 2009):

- Communion refers to interpersonal distance, self-other relation, connection, along an axe from separateness to relatedness. The connected self may be fused with others (no clear boundaries) as opposed to the separate self well defined.
- Agency refers to autonomy functioning, being an agent and acting willingly, along an axe from autonomy to heteronomy. Autonomy emphasizes self governing whereas heteronomy emphasizes governing from the outside.

This evolution leaded to some re-conceptualization such as the discussion of (Hazel Rose Markus and Kitayama 2003) about the different forms of agency, which can integrate a high degree of communion (relational agency) or not (disjoint agency).

Another personality trait often considered which is currently having the same evolution is Narcissism. Narcissism was in the first place a clinical construct viewed as a personality disorder. In contrast to this maladaptive view of narcissism, the non-pathological evaluation of narcissism – mostly measured with the Narcisstic Personality Inventory (NPI) (Raskin and Terry 1988) – tap adaptive (leadership) and maladaptive (low relatedness) aspect of the construct (Keith and Foster 2007). Narcissism is associated with high self-esteem, high agency but low relatedness: they have an inflated self-concept and neglect others (Campbell, Rudich, and Sedikides 2002). As a consequence, Narcissistic individuals are less empathic (Watson et al. 1984) have worst emotion regulation abilities (Jonason and

Krause 2013) and are more extroverted and less agreeable (Holtzman, Vazire, and Mehl 2010). In line with these findings, (Konrath, Bushman, and Grove 2009) found narcissism association with the interaction between independence and interdependence from the SCS: high independence associated with low interdependence was related to narcissism. It is very recently that the notion of communal narcissism was proposed by (Gebauer et al. 2012) where agentic narcissists is characterized by individuals satisfying self-motives of grandiosity, esteem, entitlement, and power in agentic domains and communal narcissists is characterized by individuals satisfying the same self-motives in communal domains. The discussion about their differences help to better capture the possibility of a communal narcissism: "*Agentic narcissism may be understood as an agency-agency trait: an agentic trait that is expressed through agentic means. An inspection of items from the Narcissistic Personality Inventory indicates that this inventory indeed captures our reasoning. At the trait level, the NPI assesses the disposition to hold grandiose self-views—an agentic trait. At the means level, the NPI is also relevant to agency. In particular, NPI items reflect grandiose self-views on key components of agency, such as assertiveness ("I am assertive"), competence ("I am more capable than other people"), and authority ("People always seem to recognize my authority"). Paralleling this reasoning, communal narcissism may be understood as an agency-communion trait: an agentic trait that is expressed through communal means. Key components of communion are helpfulness, interpersonal warmth, and trustworthiness. Arguably, these traits can serve as means to express grandiose narcissism. For example, a communal narcissist would be a person who grandiosely views himself as "the most helpful person he knows," "the most caring person in his social surroundings," and "extraordinarily trustworthy"*" (Gebauer et al. 2012).

Emotion regulation

Inherited from attachment theory, a common idea within the two polarities models is the underlying idea of an ideal mature self which manages both relatedness and autonomy. This optimally functioning self is associated with a secure attachment style and good ability in emotion regulation (contrarily to other patterns of attachment). Therefore, emotion regulation is assumed to be directly related to this two polarities model of personality (Griffin and Bartholomew 1994). Regarding our proposed model of empathy in the previous section, emotion regulation play a key role in differentiating self oriented response (personal distress) and other oriented responses (empathic concern). To articulate our empathy model to a two dimension model of personality, it is of primary importance to know if emotion regulation can be predicted by both self-definition and relatedness. Various studies examined the relationship between alexithymia and adult attachment styles revealing moderate associations between the constructs. (Montebarocci et al. 2004) found moderate correlations (from 0.18 to 0.45) between the five subscales from the Attachment Style Questionnaire and the affect-related subscales of the TAS20 (DDF and DIF). In (Wearden et al. 2005), alexithymia was positively associated with attachment anxiety but was unrelated to attachment avoidance. When investigating the TAS20 subscales, (Meins, Harris-Waller, and Lloyd 2008) also found associations between affective alexithymia and attachment anxiety, but also found an association between attachment avoidance and Externally Oriented Thinking (EOT). In line with these findings, (Vanheule, Meganck, and Desmet 2011) found that only EOT was associated with social detachment, calling for further conceptual distinction between the affective (DDF and DIF) and cognitive (EOT) aspects of alexithymia. One study investigated the associations between alexithymia and the dimensions –independence and interdependence – of the Self Construal Scale (SCS) (Konrath et al. 2011). High interdependence and low independence are associated with affective alexithymia (DIF and DDF), EOT being less consistently negatively related to independence. These findings are in line with the idea that both independence and interdependence are necessary for optimal functioning and associated with good emotion regulation skills. However, these associations are only moderate and can hardly be merged: although emotion regulation is not independent from the two polarities view of personality, it is distinct with well defined discriminant validity (Bagby et al. 2006). It seems therefore reasonable to consider emotion regulation as a third dimension rather than embedded in the two dimensional space of self-definition and relatedness.

Optimal functioning models

Some models propose to directly assess this optimal functioning by considering its underlying dimensions. (Bekker and van Assen 2006) proposed the concept of autonomy-connectedness which is used to describe the capacity for being on one's own as well as for engaging satisfactorily in relationships with others. In this view, autonomy and connectedness are inseparable dimensions: they attempt to measure the capacity to be autonomous while being connected with others. They associate this dimension with the insecure/secure dimension of attachment theory (which is the diagonal of the two polarities model of personality) (Bekker, Bachrach, and Croon 2007). They designed a questionnaire composed of three subscales: self-awareness (SA) which is the capacity to be aware of one's own opinion, wishes and needs, sensitivity to others (SO) which is the sensitivity to the opinions, wishes and needs of other people, and capacity for managing new situations (CMNS) which is related to easy feelings in new situations, flexibility, inclination to exploration. One study investigated the associations between these subscales and the dimensions –independence and interdependence – of the Self Construal Scale (SCS) (Bekker, Arends-Tóth, and Croon 2011). Results show that independent self construal contributed positively to capacity for managing new situations as well as self-awareness. In addition, interdependent self construal contributed positively to sensitivity to others and negatively to self-awareness. If we consider SA as very close to emotion regulation and alexithymia (Moriguchi et al. 2006), these results are in line with previous consideration: emotion regulation is not independent from the two polarities model (positively associated with self-definition and negatively associated with relatedness), but is an important third dimension with good psychometric properties as in the Autonomy-Connectedness Scale (Bekker, Bachrach, and Croon 2007).

Another model coming from family therapy provide a similar approach: the Bowen model of differentiation (Bowen 1966). According to Bowen, family members can be more or less differentiated and this family characteristic is stable over time. The essence of the concept is as follow: "*The more differentiated a self, the more a person can be an individual while in emotion contact with the group*" (Winek 2009). Accordingly, (Skowron and Friedlander 1998) emphasized the intra and interpersonal dimensions of the concept: "*Differentiation of the self is defined as the degree to which one is able to balance a) emotional and intellectual functioning, b) intimacy and autonomy relationships*". Self-definition, relatedness as well as emotion regulation are important aspect for the adaptive functioning of a family. At the intrapersonal level, differentiation of the self is considered associated with the ability to distinguish thoughts from feelings and therefore related to flexible coping. Poorly differentiated individuals tend to be emotionally reactive, and subject to personal distress in response to emotionality of others. At the interpersonal level, differentiation of the self implies the maintenance of a clearly defined sense of self, with "*flexible boundaries that permit emotional intimacy*". The questionnaire designed to assess differentiation of the self – Differentiation of the Self Index (DSI) includes four scales: Emotional Reactivity (ER), Emotional Cutoff (EC), Fusion with Others (FO) and ability to take an I Position (IP). Emotion reactivity and emotional cutoff are directly associated with the difficulty to handle affect. The fusion with other scale seems more related to relatedness (interpersonal distance) while ability to take an I position is clearly associated with an agentic definition of autonomy. Attachment theory is also a framework for understanding how internalization of family origin experiences facilitates the development of the self-regulation. (Skowron and Dendy 2004) found that the four subscales of the DSI explain 40% of the variability in attachment anxiety and 62% of the variability in attachment avoidance revealing considerable overlap between the two systems: "*these findings suggest that while the concept of attachment security and self differentiation tap distinct dimensions of relational experience, they also share at least two similar, underlying dimensions, namely the dialectic need for intimacy and autonomy in human experience*". Interestingly, the two scales associated with emotion regulation (ER and EC) were differentially associated with attachment style: Emotional reactivity was associated with attachment anxiety and Emotion cutoff with attachment avoidance. One possible interpretation is to consider ER and EC not as emotion regulation but as two different consequences of and underlying emotion regulation deficit: ER seems more related to personal distress while in connection with others and EC seems more related to interpersonal distance, an autonomous self marked by poor emotion regulation. Taken

as such, it appears relevant to consider separately emotion regulation from self-definition and relatedness aspects of the self.

Summary

This section detailed how a definition of autonomy in terms of agency enables to conceive the orthogonality with the communion dimension. While some authors argue that these fundamental dimensions are value free (no ideal position within the circumplex model), some other theories inherently consider that an ideal self should be high on both communion and agency. This is the case of the attachment theory (i.e., secure attachment is ideal) but also other models such as the autonomy-connectedness model (Bekker, Bachrach, and Croon 2007) and the differentiation of the self model (Skowron and Friedlander 1998). These models clearly aim at describing adaptive and maladaptive identities giving a key role to emotion regulation: the individual should be able to connect with others without fusion and being overwhelmed by emotions. Given the variability in background of all these approaches and the novelty of integrative proposals, it is not possible to draw a clear picture of how communion, agency and emotion regulation are articulated toward an optimal functioning. However, the fact that all three are key elements of the interpersonal functioning is already interesting.

2.3.5. Five Factor model of personality

The Five Factor model of personality is by far the most used personality framework. Although a shift in perspective was necessary and possible thanks to interpersonal theories of personality, we can now reconsider the FFM traits with regard to the interpersonal domain. Within the FFM, three traits are potential implications in the social sphere: Agreeableness, Extraversion and Neuroticism.

Agreeableness is often associated with being sympathetic, generous, forgiving and helpful: "*the behavioral and structural aspects of Agreeableness can be explained by differences in the underlying motivation for maintaining positive relationships with others*" (Graziano et al. 2007). It has also been associated with interpersonal accommodation (Robinson, Watkins, and Harmon-Jones 2013). Another important aspect of Agreeableness is emotion regulation: "*It is unlikely that people engage in sacrifices and costs of prosocial behavior unless they believe they are able to master the emotions associated with the recognition of other's needs*" (Caprara et al. 2010). Thus, Agreeableness include the ability to "*moderate or suppress the dominant self-centered emotions like personal distress so that subdominant, other oriented empathic concern can be expressed*" (Graziano et al. 2007). This close relationship with sympathy (prosocial orientation and good emotion regulation) has been confirmed by the recurrent high correlations between Agreeableness and the Empathic Concern scale from the IRI (Robinson, Watkins, and Harmon-Jones 2013). A theorization of this trait including motivations and processes has been proposed making this trait more "*dynamic*" as discussed earlier (Robinson, Watkins, and Harmon-Jones 2013). This trait has also been associated with the communion axis of interpersonal theories of personality, but its inherent emotion regulation component makes it distinct.

Extraversion is a trait marked by a strong engagement with the external world: extrovert people enjoy talking, are full of energy and assert themselves (Costa and McCrae 1992). Early in the creation of the circumplex approach of personality this trait was associated with the dominance axis (Trapnell and Wiggins 1990). However, more recent account of extraversion consider that both agency and affiliation compose this trait (Do and Minbashian 2014). The affiliation component is particularly salient in the fact that extrovert have high sociability and experience positive relationships. However, the sociability aspect of extraversion have been argue to be a consequence of more fundamental component of extraversion, such as reward processing (Lucas et al. 2000) or a tendency to attract social attention to assert themselves (Ashton, Lee, and Paunonen 2002). The precise association with affiliation is still an

active research question (Smillie 2013). A recent study investigated how agreeableness and extraversion are associated with satisfaction in social relationships (Tov, Nai, and Lee 2015). Interestingly, they found that the reason why extroverts are satisfied was their greater trust in other whereas agreeable individuals were satisfied thanks to less frequent negative exchanges. Together, these indicate that extraversion is associated with sociability but more as a consequence of its interpersonal functioning. Still, extraversion can be considered close to the agency axis.

Neuroticism is also called emotion instability and refers to a tendency to experience negative emotions. Neurotic individuals are emotionally reactive and anxious. Defined as such, neuroticism is not directly related to the interpersonal domain: indirectly it impairs personal relationships through the maladaptive role of negative emotions (Costa and McCrae 1992). A more insightful interpretation of neuroticism in the interpersonal domain can be found in its association with self esteem. In a seminal paper, (Judge et al. 2002) revealed how self-esteem, neuroticism, locus of control, and generalized self-efficacy could be considered as measuring the same construct given their lack of discriminant validity. Complementarily, self-esteem has been conceptualized as a monitoring system (the sociometer hypothesis) of others' reactions and alerts the individual to the possibility of social exclusion (Leary et al. 1995). An individual with low self-esteem will see more ego-threat in other's reactions and therefore experience more social anxiety, as for neuroticism. Within this interpretation of neuroticism, this trait could be used in situations where the self is threatened and help differentiate anxious reactive individuals from less reactive individuals.

2.3.6. Conclusion

Based on the finding that interdependent self-construal has been association with bodily interpersonal processes, we began a review of related personality constructs. We acknowledge the difference of nature between a general descriptive description of personality as in the FFM and more process-based approach of personality including structure and motivation aspects. As described by (Aidan G. C. Wright 2011), process based theories are in the direction of a more dynamic conceptualization of personality. Another conclusion of this review is that the construct of self-construal can be located within the larger and integrative framework of two polarities models with a common structure: agency and communion as the two basics axes. Each is a fundamental need/motivation. The structure and processes articulating behaviors around these axes are still unclear: the current literature is diverging and very recent. For the purpose of this thesis, we can consider as a strong basis the two dimensional structure, agency and communion being orthogonal.

Surprisingly, the literature on interpersonal theories of personality is almost never confronted to experimental social psychology. Thus, it appears difficult to draw precise hypotheses linking the two dimensions to identified interpersonal processes (behavior matching and interactional synchrony). Following the already existing results from the interdependent self-construal, we can hypothesize that communion related constructs will be associated positively with the intensity/amount of interpersonal coordination, more communion underlying a volition to form social bond. Regarding agency, the literature about independent self-construal tells us that it inhibits interpersonal processes. Another possible effect would be possible in situation where uncertainty and leadership might come at play: an agentic person might be more willing to take the lead.

Also, the review of theories incorporating an adaptive component to their models was informative about the key role of emotion regulation in the interpersonal functioning. Although some authors tend to consider emotion regulation as the diagonal of the two dimensional model (being high in agency and communion is assumed to be high in emotion regulation), results from the literature and other theories highlight the complementary role of emotion regulation.

Lastly, we took another look at the FFM traits and evidenced potential interests for interpersonal situations and similarities with the two dimensional models.

2.3.7. Articulation of individual differences from empathy and interpersonal theories

This review of individual differences based on interpersonal theories of personality confirmed and enlarged the framework presented in the section on empathy. Firstly, what we previously called pro-social orientation can be assimilated to the communion axis of the two polarities models. Thus, we assume that various communion related variables (e.g., pro-social value orientation, interdependent self-construal) would have the same location in the model: fostering empathic concern. Additionally, we evidenced the validity to consider emotion regulation as relatively independent from communion and agency. In our model, emotion regulation decreases personal distress and fosters empathic concern.

At a first glance, the association between the agency axis and the three empathic traits appears unclear. Also, perspective taking seems relatively independent from it and is associated with cognitive empathy: the tendency to experience perspective taking induces more empathic concern and is possible via emotion regulation. However, some very recent re-conceptualization of the social nature of agency provides a slightly different picture. We previously characterized agency as a goal-pursuit of the self, striving to master the environment. (Gillespie 2012) went in more details in this definition: "*Human agency can be defined as the degree to which an agent can act independently of the immediate situation. This sociocultural definition, which stems from Dewey and Mead, emphasizes not only the power to act, but the degree to which an action is motivated by concerns originating outside of the immediate situation. The immediate situation is the here-and-now perceptual and experiential situation which arises as a function of the agent's immediate impulses combined with situational affordances, demands and constraints. The organism without agency is compelled to act by stimuli in the immediate situation. But, the organism with a degree of agency stands apart from the immediate situation and can be motivated by concerns beyond the situation, such as a distant goal, an abstract principle, or concern for someone else*". With this definition, A. Gillespie put at the center of agency the ability to take a distance from the situation. Proposing a theory of "*position exchange*", he describes a process of perspective taking development through the experience of intersubjectivity: by undertaking cooperative activities, individuals enter in a process of taking the perspective of the other developing the sense of agency (Gillespie and Richardson 2011). Following this definition, perspective taking development requires an enhance motivation to cooperate (communion) and is associated with an enhance sense of agency. This approach appears to well explain why perspective taking is associated with student leadership (Dugan et al. 2014) while at the same time being associated with social motives (Gehlbach, Brinkworth, and Wang 2012). This view of perspective taking seems also in adequation with the ontogenetic/phylogenetic description of empathy from (Waal 2012) where perspective taking is a more mature aspect of empathy compared to empathic concern: in addition to require emotion regulation and communion motives, it induces an enhance sense of agency. While empathic concern relate directly to other's emotion and being moved by them, perspective taking enables the individual to purposely move into the others' perspective. Figure 28 summarizes these propositions.

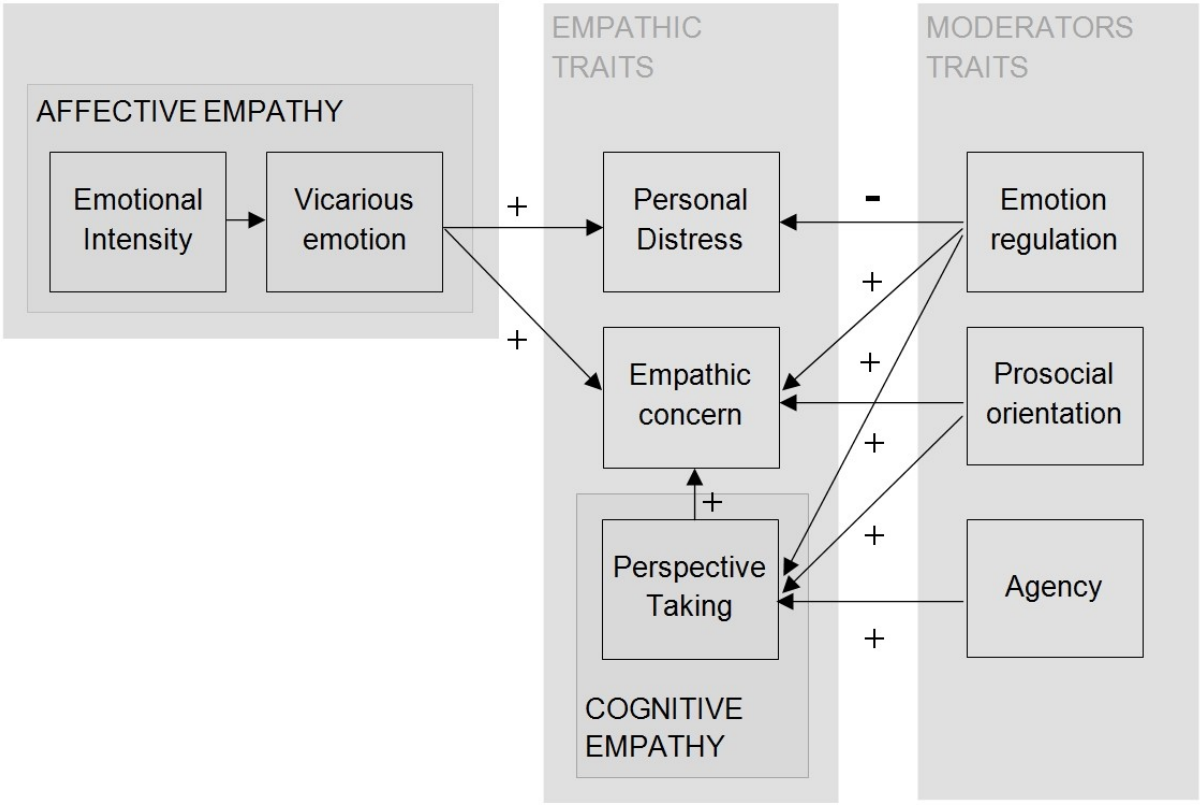


Figure 28: Revised version of our summarizing model HIDID

2.4. From personality to cognitive style: Field dependence/independence

The last type of individual difference highlighted in the section on interpersonal processes is the cognitive style of field dependence/independence. The previously reviewed individual differences referred to personality traits (e.g., agreeableness) and socio-emotional abilities (e.g., empathy) all assessed by means of self-report questionnaires. Although all these assessment tools are built in order to ensure their validity against less subjective evaluations, they still suffer a certain distance from the functioning of individuals. In the early 1950s, the psychological concept of cognitive styles emerged in an attempt to fill this gap: "*cognitive style historically has referred to a psychological dimension representing consistencies in an individual's manner of cognitive functioning, particularly with respect to acquiring and processing information*" (Kozhevnikov 2007). They were conceptualized as stable and value free which means they were considered as styles rather than abilities, with the explicit aim to understand "*the relations of personalities to their environment*" (Kozhevnikov 2007).

One of the most studied cognitive styles is that of Field Independence and Dependence (FID, FI for Field Independent individuals and FD for Field Dependent individual) (Huteau 1987) with 4400 published articles about it in 1975 (Huteau 1987). At the origin FID was assessed with the Rod and Frame Test (RFT), a test of perception of the vertical, and assumed to reveal differences in the tendency to rely more (FD) or less (FI) on external (visual) cues rather than internal (bodily) cues. Since the original conceptualization, a tremendous number of studies have enlarged the nomological framework of FID and various re-conceptualization have been proposed to account for these findings (H. A. Witkin and Goodenough 1981).

The construct of FID is particularly interesting for this PhD thesis for three reasons:

- In addition to being related to various interpersonal behaviors (Herman A. Witkin and Goodenough 1977), FID has been recently associated directly with behavior matching tendencies (R. B. van Baaren et al. 2004)

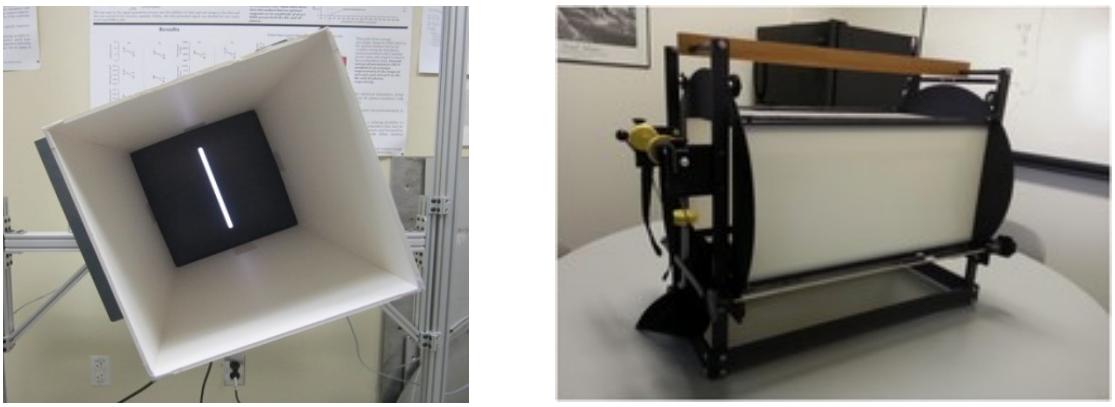
- FID is directly associated with ways of related to the world, such as postural control strategies (B. Isableu et al. 1997) which might enable to draw hypotheses about bodily interpersonal behaviors
- FID, as a measure of perceptual independence from the visual field, seems close to the definition of agency given by (Gillespie 2012)

However, the concept of FID is still a slippery construct with many weakness and unclear aspects. Recent uses of FID seems to limit their interpretation of the concept to the interpretation which best fit their results without a critical review of it. In the following, we first review the development of the FID concept and its associations with interpersonal phenomena as it was understood in 1979. It is important to note that the vast majority of works on the FID was made during the life of Herman Witkin, the research who initially discovered and conceptualized the effect. In the early 1980s, several large reviews provided a unified big picture of the findings. The two first sections refer to this synthesis. After this period, the development of cognitive styles turned away from the FID concept, moving toward higher level and complex cognitive functions and growing in an atomized way. (Kozhevnikov, Evans, and Kosslyn 2014) write: "*despite very popular in 1950s-1970s, research on cognitive styles has been seriously questioned in recent decades. Currently many cognitive scientists appear to believe that research on this topic has reached a standstill.*" Concerning the FID concept, in our view its decline resides in some inherent and unsolved methodological issues of FID measures, leading to some misinterpretations. This point is detailed in the section validity issues. We finally review current uses of the FID which most of the time do not consider past debates, and show how a re-conceptualization of the FID construct clarify the literature and generate new research questions.

2.4.1. Evolution of the concept

The Internal/External Referent hypothesis (IER)

To determine the vertical of the word, we align our body (egocentric frame of reference) on different vicarious frames of references (FoR) that are specified by vision, proprioception (vestibular and somatosensory cues). FoR are said vicarious because they are equiprobable in low tasks constraints, so that we can orient our body either on visual or on proprioceptive based ones in an equiefficient manner (B. Isableu et al. 1997). In the 1940s, Herman Witkin and his team began a research program to investigate how we differently use these various sources of information for establishing the upright. In this purpose, they developed the RFT and evidenced large individual differences (H. A. Witkin and Asch 1948). In the Rod and Frame Test, the participant has to orient a rod to the word vertical by rotating it. The difficulty resides in the fact that the participant's head is within a paving stone hiding every visual reference to the word vertical apart from of the square frame of the paving stone (Figure 29). In the test, the square frame is tilted (e.g., 18°) to provide on erroneous visual information. To adjust the rod to the word vertical, the participant should rely on his/her bodily sensations (vestibular and proprioceptive information) without considering the square frame.



a b

Figure 29: a) display of the rod inside the rectangular optical tunnel b) external view of the rod and frame apparatus

Results to this perceptual task revealed markedly differences in the performance of the RFT which were consistent across trials acknowledging a preferred way to integrate the diverse sources of information available to locate the upright: participant aligning the rod toward the square frame were labeled FD and participant aligning the rod toward the word vertical were labeled FI. Other type of tests such has the Body Adjustment Test (adjusting the body rather that the rod) and the Rotating Room Test (adjusting the rod in a rotated room) confirmed this tendency of inter-individual differences. Over the various possible explanations, Witkin and colleagues found out that the most consistent and with greater potential value for future research was that "*individual differences we had observed represented differences in the tendency to use the external visual field or the body itself as a primary referent for perception of the upright*" (H. A. Witkin and Goodenough 1981).

The Analytic/Holistic Processing hypothesis (AHP)

The second step in the conceptualization of FID came with the discovery of the positive correlation between the RFT and the Embedded Figure Test (EFT).

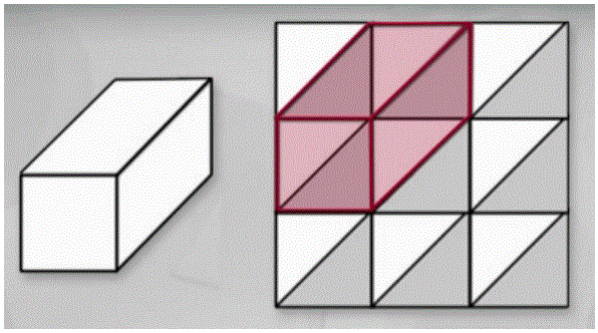


Figure 30: example of figure to find in the EFT

The test requires the participant to identify a simple figure within a more complex figure such that "*the latter create a gestalt within which the part is hidden*" (H. A. Witkin and Goodenough 1981) (Figure 30). Participants have to do it on several different figures in a given time, their overall scores being calculating as the number of correct responses. The EFT is assumed to measure the ability to identify an element from an organized and articulated field, a gestalt. The participant should disembed the simple figure from its surrounding context.

From this findings, results at the RFT were re-conceptualized as a disembeding performance: the FD participant take the field (rod plus square frame) as a whole without restructuring it, in a holistic manner, whereas FI participant actively isolate the rod by perceptually restructuring the field, in an analytic manner: "*to analyze and structure the field is to show articulated cognitive functioning as a characteristic approach to the field; to follow the field as given is to use a global approach*" (Huteau 1987). In addition to the articulated/global and analytic/holistic opposition characterizing this approach, the duet active/passive was considered: to have an articulated way of apprehending the

field is to actively restructure it instead of passively take it as a whole. Since this finding, the RFT and the EFT are used interchangeably to assess FID. Some variants of these two tests, for children or for groups for example, were also designed. As the EFT is a paper and pencil test, most of recent studies use it as a FID measure. Also, the fact that the same construct (FID) could be assessed with two different perceptual tests was taken as an evidence of a more general individual difference in cognitive functioning. The term cognitive style was associated with FID.

As a cognitive style, FID (measured by the EFT or RFT) gained a considerable increasing interest and a wide array of associations was evidenced. FID was linked to more complex cognitive phenomenon extended its predictive power outside the perceptual realm. FID was found to predict response to some memory tasks, learning processes and creativity performance (Huteau 1987).

The Psychological Differentiation hypothesis (PD)

The third conceptualization of FID came from the discovery of the influence of FID on various socio-affective phenomena. Individual differences in FID were found to be related to the body concept (assessed by the analysis of children drawings): being more FI leading to have a more articulated body concept (Faterson and Witkin 1970). As "*the typical progression in development of the body concept is from a relatively global view of the body, to awareness of its constituent parts and their interrelatedness, as well as of the outer limits of the body*" (Herman A. Witkin, Goodenough, and Oltman 1979), differences in FID were associated to a difference in maturity of the body concept. However, other approaches to the body concept and body boundaries found inconsistent evidences (e.g., (Siegel 1977)) leading authors (Herman A. Witkin, Goodenough, and Oltman 1979) to consider this research direction with caution. Another more consistently evidenced line of research is the tendency for FI to have a sense of separate identity, operationalized in self-object differentiation (e.g., (Olesker 1978)), autonomy in interpersonal situations under conditions of ambiguity (e.g., (Solar, Davenport, and Bruehl 1969)) and higher level a tendency of FD to favor interpersonal oriented career compared to FI (e.g., (H. A. Witkin et al. 1977)). The last line of research contributing to a re-conceptualization of the FID construct comes from the evidence that FI individuals have more specialized cognitive activities and affective experiences than FD. (Herman A. Witkin, Goodenough, and Oltman 1979) argue that this specialization is characteristic of the development of children where "*as the child grows older, structured systems of control are developed that make possible the specific channeling of impulse*". Thus, the specification of psychological function avoid the "*too easy mixing of the ideational, affective, motivational and motoric*" often leading to less impulsive reactions in emotion discharge (e.g., (Podell and Philips 1959) and more specific defense in arousing conditions (e.g., (Almgren 1971)). This array of tendencies made Witkin and colleagues to propose a higher order factor which could explain their relations: the psychological differentiation. Coming from biology to describe formal properties of organism systems, the differentiation can be defined in a broad sense as the complexity of a system structure. A non-differentiated system is relatively homogeneous. Applied to FID findings, (Herman A. Witkin, Goodenough, and Oltman 1979) describe it as such: "*a system that is more differentiated shows greater self-nonself segregation, signifying definite boundaries between an inner core of attributes, feelings, and needs identified as the self, and the outer world, particularly other people. In a less differentiated system, in contrast, there is greater connectedness between self and others. […] A system that is more differentiated is also characterized by greater segregation of psychological functions; that is, functions are more separate from each other and activities within each are more specialized*". The precise position of the FID construct within the concept of differentiation has been refined twice to account for accumulating findings. Figure 31 present the last one proposed in (Herman A. Witkin, Goodenough, and Oltman 1979) where FID is separated from the "*specialization of psychological functions*": FID is more directly related to cognitive restructuring and interpersonal competencies.

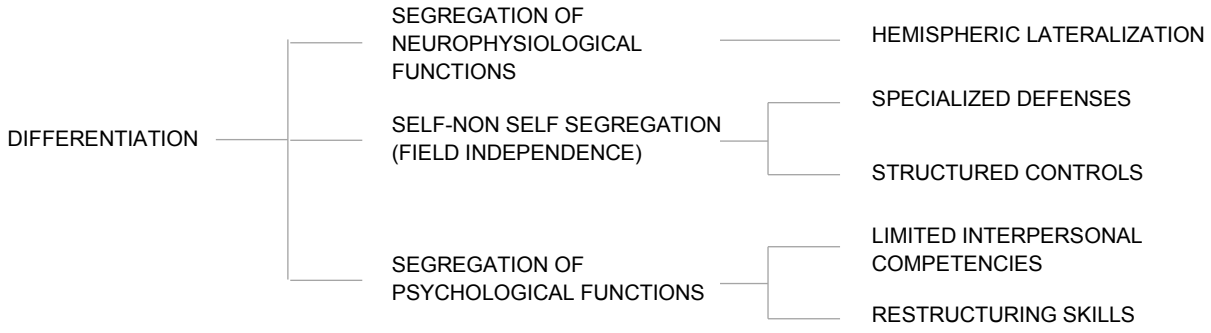


Figure 31: Final theorization of the differentiation hierarchical organization (Herman A. Witkin, Goodenough, and Oltman 1979)

In 1979, Herman Witkin die leaving behind him extensive reviews of the FID research program (H. A. Witkin et al. 1977)(Herman A. Witkin and Goodenough 1977)(Herman A. Witkin, Goodenough, and Oltman 1979)(H. A. Witkin and Goodenough 1981)(Huteau 1987). These integrative reviews provide a framework with a sense of unification. After this prolific period, the research issue of locating the FID within the framework of differentiation was not pursued leaving this body of work somehow incomplete, as more generally for the movement of cognitive styles (Kozhevnikov 2007). Modern uses of FID in psychology undertake one of the three possible interpretations of FID – Internal/External Referent (IER), Analytic/Holistic Processing (AHP) or Psychological Differentiation (PD) – assessed by either the EFT or the RFT as independent variables interchangeably without making it their central research question.

2.4.2. FID in the interpersonal domain

Perhaps one of the main reason that FID was the most investigated cognitive style is that its influence goes well beyond mere cognitive functioning (Herman A. Witkin and Goodenough 1977). Results from studies investigating FID in the interpersonal domains can be organized along three categories: FID influence in the preferences for interpersonal situations, in the use of social cues as references and in interpersonal behaviors.

Interpersonal situations

FID has been found by some studies to differ as a function of social situation preferences defined by sports practice or career orientations. In sports, FD have been found to prefer the practice of collective sports such as volley ball in comparison to dance (Bard 1972) or tennis in comparison to athletics (Barrell and Trippe 1975). However, in (Barrell and Trippe 1975) no differences in soccer or cricket were found. These results should also be contrasted regarding an alternative hypothesis which explain sports preferences as a function of their requirements on open and closed skills (Mcleod 1985). Regarding career orientation, (H. A. Witkin et al. 1977) provided an extensive review showing how FD favor career with social content, meeting people and requiring to persuade, whereas FI do not consider such characteristics. Instead, they favor career requiring more analytics skills such as computing or mathematics. Again, some contradictory findings exist (Savage 1983). However, (Herman A. Witkin and Goodenough 1977) say of this area of findings that it "*is clear in demonstrating that field-dependent persons show a strong interest in people, prefer to be physically close to others, are emotionally open, and favor real-life situations that will bring them into contact with people*".

Social references

Following the IER hypothesis, some authors have investigated the extent to which individuals rely on other individuals as references. Within an experiment of the autokinetic effect (effect of seeing a fixed dot in the dark moving because of the absence of referential), (Linton 1955) evidenced that FD individuals significantly relied on a confederate to adjust their choice. Complementary to this finding, (Mausner and Graham 1970) primed participant with the belief that the confederate was false or not on his/her judgment. The effect evidenced by (Linton 1955) was replicated only when the confederate was not believed to be wrong: the information source should be evaluated as reliable. This effect was found different from a conformity tendency, an effect of authority or a need for approval (McCarrey, Dayhaw, and Chagnon 1971). Finally, this influence of the other judgment was effective only in situations where the confederate was present: no effect was found about the acceptance of authoritarian statement as management recommendations (Doktor and Hamilton 1973).

In another setup, (Solar, Davenport, and Bruehl 1969) FD and FI individuals to come to an agreement about the good orientation of the rod in the RFT. They evidenced that the trade-off between the two individuals significantly tended toward the FI score, labelling FD as "*socially compliant*". Similarly, (Oltman et al. 1975) showed that in the case of conflict resolution in dyads, if one of the dyad member is FD the conflict as a significantly greater chance to be solved. In these two cases, the interaction object between the two individuals is uncertain, case in which the FD is more influenced by the other as a social reference. For (Solar, Davenport, and Bruehl 1969), FD should be considered as willing to cooperate, they are "*person-oriented*" whereas FI are "*task-oriented*" individuals.

Interpersonal behaviors

Some studies tried to unveil the influence of FID directly on interpersonal behaviors. Two studies investigated the effect of a fake interviewer who vary in behavioral styles as the independent variable – being either cold (few backchannels, few attention) or friendly (more backchannel, smiles, shared attention) – (Steingart et al. 1975) (Freedman et al. 1972). In (Steingart et al. 1975), this variable impacted the content of the monolog of FD and in (Freedman et al. 1972) the hand movements of FD were impacted. (Herman A. Witkin and Goodenough 1977) interpret these results as a need for guidance in FD individuals. A distant and cold partner put FD people in highly ambiguous situations where they lose self-control. Another way to label these differences is to say that FI are more socially autonomous than FD during social interaction.

Building on the fact that FD rely more on external social referents, some authors have investigated gaze patterns (children or adults) in different tasks. (Ruble and Nakamura 1972) show that when children have to solve a problem with an experimenter next to them solving a similar task, FD children look more at the experimenter while FI look more at the game. Complementarily, (Konstadt and Forman 1965) evidenced that this effect did not hold anymore when the experimenter make the children feel confident about the problem. This confirms what have been explained earlier: FD rely on social cues as referent only if the source of information appears relevant. These findings are more inconsistent among adults: (Nevill 1974) evidenced that FD looked more at the interviewer after a solving task whereas in meeting tasks (Kendon and Cook 1969) found no associations. No associations are also evidenced in (Frank and Kent 1982), results which can be interpreted as the lack of relevance of nonverbal signals in the task: dyad member add to guess words based on other words (pyramid games).

Lastly, (Herman A. Witkin et al. 1962) associated less differentiated individuals (FD) with greater interconnectedness. From this assumption, (Greene 1976) investigated the impact of proxemics (interpersonal distance) on behaviors. They found that only FD changed their nonverbal behaviors as a function of proxemics. Another line of research investigating emotional distance found that FD have greater tendencies to self-disclose (Sousa-Poza, Shulman, and Rohrberg 1973)(Rohrberg and Sousa-Poza 1976). It should be noted that the fact that

FD appear more socially oriented does not mean they are more socially competent: several studies have found that FID was either not associated or only FI was associated with greater emotion recognition and face recognition (Pellegreno and Stickle 1979)(Westbrook 1974)(Hoffman and Kagan 1977).

From these 30 years of research, (Herman A. Witkin and Goodenough 1977) conclude that "*field-dependent people are attentive to the views of others; they are sensitive to social cues; they have an interpersonal orientation, encompassing a strong interest in people, a preference for being with others and even being physically close to them, emotional openness and, in some circumstances, facility in getting along with others.*" We find this statement very strong regarding the literature for several reasons. Firstly, most of the studies have very low statistical power, with sample population rarely above 30 participants and the use of median split strategies to constitute FI and FD groups. Another type of researches parses a population and keeps only extreme individuals as FD and FI to enhance the results. This fact combined with the recurrent inconsistencies asks to take this body of research with caution. It seems surprising that modern psychology did not investigated further the associations between FID and interpersonal behaviors given the conclusions drawn by (Herman A. Witkin and Goodenough 1977). We hypothesize that some researchers did so but without expected successes in the context of modern psychology which favor larger sample sizes and linear analyses (e.g., correlations, regressions). Two limitations might impair recent researches on FID if not taking carefully into considerations:

- The two measures of FID (RFT and EFT) have methodological issues which should be acknowledged. They are reviewed in the section validity issues
- The nature of the task or the context is a key element in the relation between FID and social behaviors. This aspect seems to be in accordance with recent research which mostly focus on specific populations such as bomb-disposal expert (Glicksohn and Bozna 2000) or yoga practitioners (Fiori, David, and Aglioti 2014)

2.4.3. Validity issues

RFT-EFT against general abilities

The fact that most recent research works uses FID as independent variables with traditional assessment tools (RFT or EFT) without critical considerations raises major issues given the lack of validity highlighted by a number of researchers in the 1990s.

First of all, the RFT and the EFT show poor convergent validity. With a correlation of 0.4 between the two measures in average (Huteau 1987), it seems difficult to justify the character interchangeable of the two tools to assess FID. In addition, both the RFT and the EFT are not value free: they are performance test where a "*good answer*" exists (e.g., in the RFT, the orientation of the rod is computed as an error in alignment to the word vertical) which bring these two tests close to ability tests: "*instead of measuring bipolar dimensions that represent two equally efficient ways of solving tasks, in reality these tests measure only a single pole of the dimension (e.g., the EFT assesses only the level of field-independency). The result is that these tests are more like tests of spatial ability than measures of style*" (Kozhevnikov, Evans, and Kosslyn 2014). All the papers offering a critical lecture of the FID concept come to the conclusion that the RFT and EFT assess different phenomena with their shared variance explained by more general abilities rather than a preferred processing style: some authors have argued that the "*common variance is due to shared general visualization ability or even more generally to fluid intelligence*" (Goodenough, Oltman, and Cox 1987). The most striking evidence was provided in (Goodenough, Oltman, and Cox 1987) were 199 participants responded to the EFT (two different measures: standard EFT and Hidden Figure Test), the RFT (on five different versions) and other tests assessing visuo-spatial abilities. Conducting a factor analysis, they evidenced that all RFT measures loaded on the same factor labelled Orientation Constancy factor (IER hypothesis) whereas EFT measures

loaded on closure flexibility (a visuo-spatial ability very similar to the EFT: the ability to demonstrate selective attention to a specified set of elements when presented within various settings). The closure flexibility factor correlated with orientation constancy at only 0.32. From this large study, authors provide three conclusions:

- "*The RFT-EFT relationship is due to a general spatial-visual ability*"
- "*Consistent with Witkin's original view, field dependence in the standard RFT is a function of individual differences in the importance of visual cues in the maintenance of orientation constancy*"
- "*It seems prudent, therefore, to drop the term field dependence when referring to the EFT*"

In support of these conclusions, (McKenna 1984) focus on the association between EFT and three possible covariate: general intelligence, flexibility of closure and fluid intelligence (capacity to think logically and solve problems in novel situations, independent from acquired knowledge). In their review, positive significant correlations were found for the three construct, with fluid intelligence being more consistently and strongly associated with the EFT. In a complementary analysis, they confirmed this strong association with fluid intelligence and evidence the absence of consistent correlation with personality traits such as extraversion and locus of control (McKenna 1983). In the same direction, (J. A. Richardson and Turner 2000) found associations between the EFT and a new intelligence measure: the Sternberg's Triarchic Theory of Intelligence. (Milne and Szczerbinski 2009) investigated the associations between the EFT and various measures of closure flexibility. In a factorial analysis, instead of finding a one factor component which would account for most of the variance, they found a very fragmented structure where the EFT was rather isolated. This result confirms that the association between the EFT and closure flexibility exist but is not as strong as the one with fluid intelligence.

Most of the recent account of FID does only consider the measure of EFT, which seems to perform poorly on discriminant analyses from general ability tests. If one is interested in investigating individual differences in holistic versus analytic processing, new measures have been proposed recently such as (Riding and Cheema 1991) with the computerized Cognitive Style Analysis (CSA) or the Sternberg's theory of thinking styles (Sternberg 1999). Another trend in modern psychology is to consider style at a higher cognitive level to avoid perception related issues. This new kind of categorizing the way individual think about things has been labeled "*thinking styles*" and have been found to be related to school achievement (whereas the EFT was not) (Zhang 2004). In the same direction, the concept of learning style is developed to account for school learning strategies (Keefe 1987). Contrary to early conceptualization of cognitive styles, this modern trend focuses on more complex processes appearing later in developmental stages (Kozhevnikov 2007).

FID, Impulsivity and Mobility

In addition to acknowledge essential issues related to discriminant validity from ability tests, it is important to consider the possibility of confounding variables which might bias results on both the EFT and RFT: impulsivity and mobility.

The Reflection-Impulsivity dimension developed by (Kagan 1966) measure the capacity of individual to differ their responses in any task. Considered as a cognitive style, the review of its correlates and consequences are beyond the scope of this paragraph and we will focus on authors investigated the interaction between FID and impulsivity. In its review about this concept, (Messer 1976) evidenced a moderate association between FID measured by either the EFT and the RFT, FI individuals being more reflexive than FD individuals. This result is not surprising given the nature of the EFT and RFT where faster and more inaccurate responses lead to lower scores. Thus, it is possible that some individuals might be considered as FD in the EFT or the RFT as a result of their inherent impulsivity: not taking the time to process information to provide an accurate response. This effect has been confirmed in some recent works. (Rozencwajg and Corroyer 2005) reveals individuals with the tendency to respond faster were significantly more FD.

In (Glicksohn and Kinberg 2009), authors proposed to differentiate Impulsive people from FD by taking into account reaction time. However, both used as their principal measure of FID the EFT which in addition to the issues rose above show structural similarity with traditional test to evaluate impulsivity (e.g. the Matching Familiar Figure Test). Evaluating the effect of the tilted frame in the RFT on response time, (Bagust 2013) found no relationship between the frame effect and the response time. However, their results should also be used with caution as their RFT apparatus was a 2D system (instead of 3D system, more immersive) which have methodological implications (see next section).

(Wachtel 1972) put it clearly that cognitive style should be differentiated from "*style of adaptation*". In regard with this possible adaptation, H. Witkin already acknowledged the possibility for individuals "*to acquire characteristics of both field-independent and field-dependent cognitive style*" (Niaz 1987). This adaptive ability to choose or switch between cognitive styles have been coined the Mobility meta-style in opposition to Fixity (also called Rigidity-Flexibility) and has been one of the more recent trend to account for inconsistencies in the history of cognitive styles (Kozhevnikov 2007): "*because individuals' positions on the metastyle dimension define their flexibility to choose the most appropriate cognitive style, flexible individuals might exhibit a variety of styles depending on situational requirements, causing "elusive" correlations among their preferences for a particular style and performance on different cognitive tasks.*". If one individual is able to switch between styles to adapt to the task demand, scores on the EFT or the RFT might not reflect his/her cognitive style but rather his/her mobility. (Niaz 1987) proposed to use jointly the EFT and the Figural Intersection Test to identify fixed and mobile individuals, procedure used also in (T. Y. Mills 1995). Concerning the RFT, (Hansson, Ryden, and Johnsson 1986) proposed to compare scores between a standard RFT task (participant have to perform the best way they could) and a "*RFT-free*" task: participants are asked to place the rod to any position they preferred. Authors interpreted the pattern of responses in the RFT-free: a rod positioned geometrically in relation to the frame was considered as fixed FD whereas a varying rod position was associated with mobility. This procedure seems rather tentative as it seems to miss the necessary test for unveiling mobile individuals. The RFT-free might be interesting to assess the preferred way of functioning of individuals once the mobility of individuals has been assessed. But the first issue with the RFT is that it is a "*one-sided*" test: it enables to unveil the ability of individuals to rely only on their internal referent. Thus, individuals who preferred to operate on the FD mode in every day task but are mobile would well perform on the RFT and be classified as FI. This mobility could be revealed by tested the exact opposite ability: to be able to rely on external referent only. However, this question raise considerable methodological issues as it is almost impossible to decouple an individual perception from its bodily sensations.

Altogether, these two cofounding variables unveil methodological issues inherent to both the EFT and RFT. Considering the issues related to the EFT, we concentrate the following of our analysis on the RFT only. Alone, the traditional RFT can be considered as a good way to isolate FD with fixed style of adaptation from others: FI fix, FI mobile and FD mobile. The other possible risk is that within the classified FD fixed, some individuals might rather be impulsive than merely FD fixed.

Varieties of RFT apparatus

The RFT originally developed by the team of Herman Witkin is a fairly big apparatus principally due to the large rectangular optical tunnel: this one should be large enough to enable the participant to put his/her head inside. The frame of the RFT being made by the paving stone, this type of RFT has been designated as 3D RFT (the frame is not only a 2D square around the rod). A portable version of the RFT was designed by (Oltman 1968): only the size of the overall system differed from the Witkin's version to respect the perceptual size of the rod and the frame. Various alternatives have been proposed to simplify its use, proposing computerized version with various sizes, type of frames (3D, 2D) and type of rods (rod, two dots) (Reger et al. 2003)(Bagust 2005)(Bagust, Rix, and Hurst 2005)(Brice

Isableu et al. 2008)(Takasaki et al. 2012). Consistently, the reported frame effect was lower for 2D versus 3D version models (explained by the perspective cues and gradient textures of the rectangular optical tunnel)(Brice Isableu et al. 2008) and lower for smaller version (in perceptual angular size) than bigger standard versions (Spinelli et al. 1995). The discussion in details of the possible differences in perception processes underlying the varieties of RFT is beyond the scope of this PhD thesis but a basic understanding might help to choose the appropriate RFT method. According to (Zoccolotti, Antonucci, and Spinelli 1993), the frame effect is a dual processes involving Visuo-Vestibular Interaction (VVI) and purely Visual Mechanisms (VM) sometimes called orientation contrast. In the study of (Goodenough, Oltman, and Cox 1987), the small RFT load on a different factor (called orientation contrast) from the five other large RFT loading on a factor called orientation constancy, the difference being accounted by the fact that VVI come into play only in large RFT (thanks to peripheral cues). (Spinelli et al. 1995) found similar results acknowledging "only moderate overlap" between the two sizes of RFT, adding some complexity in terms of VM mechanisms. About the key role of VVI operating in large RFT, (Cian, Raphel, and Barraud 2001) conclude: "there is a considerable body of evidence to support the view that the influence of the tilted frame, particularly one of large angular size, is the direct neurophysiological outcome of a simulation of the peripheral retina".

Conclusions

Originally, cognitive styles are bottom up ways of apprehending cognition, from the perceptual level to more complex information processing dimensions. This unification between different level of information processing under the same construct (here FID) has been possible through the assumption that RFT and EFT tools measure the same concept. Given our review, this hypothesis appears hard to hold today. The common variance between the RFT and EFT (about 20%) seems to be accounted by general abilities such as fluid intelligence. Uses of FID in modern psychology are sparse, most of the time not acknowledging this past issues and debates. In our view, the EFT based cognitive style line of research should be distinguished from the study of individual differences in the RFT which is more directly grounded in our way to perceive the environment with our whole body. Recent investigations of FID reviewed in the next section appear to strongly agree with such proposition. In the following, to contrast with the EFT definition of a cognitive style, we consider that the RFT reflect more a perceptual style of processing sensory information with respect to a preferred frame of reference.

Remark: the shared variance might be due to VM in RFT which appear both in small and large RFT, and more closely related to EFT visual mechanisms. If it is true, this variance should be removed from the RFT to isolate the effect of VVI mechanisms, more related to what we think is a perceptual style.

2.4.4. Recent account of FID

The area of cognitive styles, after a long period of atomization, has been very recently brought together into a unified framework in (Kozhevnikov, Evans, and Kosslyn 2014)(Sternberg 2014). Authors propose to integrate the concept of cognitive style with contemporary theories of information processing from cognitive psychology and neurosciences by showing that "*research in cognitive style in psychology, in cross-cultural neuroscience, on learning styles in education, and on decision styles in business and management all address the same phenomena: environmentally sensitive individual differences in cognition that develop as a result of adaptation to physical and socio-cultural events and circumstances*". Figure 32 represent represents a proposition of classification of "*the most commonly used 19 style dimensions identified in cognitive style research*" (circles represent traditional cognitive styles, rectangles represent learning and decision-making styles) according to levels of information processing and "*distinct families of styles corresponding to different types of adaptations*".

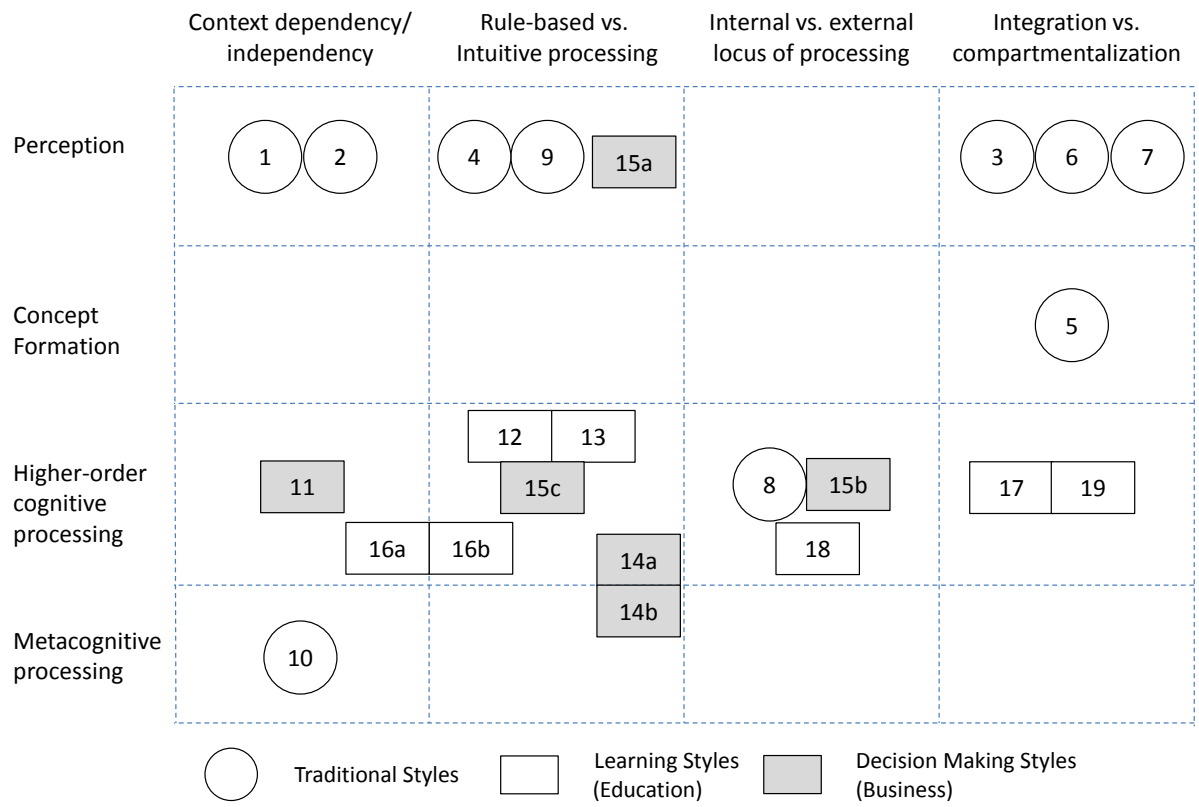


Figure 32: Cognitive style matrix representing the most common traditional and applied styles. 1. 1. Field-dependence/independence (Witkin, 1954); 2. Field articulation (Messick & Fritzky, 1963); 3. Leveling-sharpening (Klein, 1951); 4. Range of scanning (Gardner et al., 1959); 5. Breadth of categorization (Gardner et al., 1959); 6. Tolerance for unrealistic experience (Klein & Schlesigner, 1951); 7. Holist-serialist (Pask, 1972); 8. Locus of control (Rotter, 1966); 9. Reflexivity-impulsivity (Kagan, 1966); 10. Mobility/fixity (Witkin et al., 1962); 11. Adaptors-innovators (Kirton 1976); 12. Convergent-divergent (Kolb, 1984); 13. Rational vs. experiential (Epstein, Norris, & Pacini, 1995), 14. (a) Analytical vs. intuitive and (b) Integrated or high analytical/high intuitive style dimension (Agor, 1984.1989; Hodgkinson & Sadler-Smith, 2003); 15. MBTI (a) sensing-intuition, (b) introversion-extraversion, and (c) thinking-feeling dimension (Myers, 1976). 16. Gregorc's (a) abstract-concrete and (b) ordering dimension (Gregorc, 1979, 1982, 1984); 17. Deep vs. surface approaches (Biggs, 1987; Entwistle & Ramsden, 1983; Vermunt, 1994); 18. extrinsic/intrinsic motivation (Biggs, 1987); 19. Tolerance for ambiguity (Kirton, 2004; Wilkinson, 2006).

Within this cognitivist / information processing perspective on cognitive styles, the construct of field-dependence/independence proposed by Herman Witkin is presented in a unified manner as related to a context dependence/independence mode of adaptation at the perceptual level. Not surprisingly, this account for the FID literature is more related to the EFT based analyses. Merging FID in such a large high level framework does not help to clarify the FID literature and seems more to encourage dropping classical and debated measures in favor of more recent assessment tools. However, we argue that FID as still some insightful contributions to offer to the understanding of human adaptation, but it requires to critically considering the discriminant aspects of the EFT versus the RFT.

Most of the works using the EFT measure of FID base their argumentation on individual differences in information processing: FD having a more holistic/global cognitive functioning and FI having a more analytic/local cognitive functioning. For example, (R. B. van Baaren et al. 2004) write: "*it is therefore conceivable that a greater reliance on contextual cues will be associated with more nonconscious mimicry of the behavior of one's interaction partner*". One line of research which fostered researches on the association between EFT scores and interpersonal phenomena comes from cross-cultural analysis. In a seminal paper, (Nisbett et al. 2001) provide a detail analysis of the difference in "*systems of thought*" between East Asians – found to have holistic cognition – and Westerners – found to have analytic cognition –. Ten years of research seems to confirm this hypothesis (Goh and Park 2009). This difference

between supposed collectivist and individualist cultures comes in addition to the difference in self-construal highlighted by (Hazel R. Markus and Kitayama 1991): East Asians are more interdependent in their way to define themselves in relation to others. This co-variation of self-interdependence and cognitive style leaded some authors to consider cross-cultural research as another evidence of the social dimension of FID (Konrath, Bushman, and Grove 2009). In their review of this hypothesis, (Varnum et al. 2010) write: "*a large body of literature has demonstrated that cultures which differ in social orientation also show corresponding differences in cognitive style […]. On the basis of such evidence, it has been proposed that differences in social orientation are the driving force behind cultural differences in cognition*". Combining this cross-cultural co-variation and evidences from priming studies (priming independence lead to analytic cognition), authors conclude that this hypothesis is likely to be true. However, recent studies assessing this association at a within-culture level contradict this proposition. (Na et al. 2010) "*show that differences in social orientation and in cognition that exist between cultures and social classes do not necessarily have counterparts in individual differences within groups*". Using 10 different measures of independence/interdependence social orientation and 10 different measures of analytic/holistic cognitive style, they found coherent differences between groups, but no correlations among the measures. Running as a headline "*independent and interdependent self-construal do not predict analytic or holistic reasoning*", (Marquez and Ellwanger 2014) reveal no correlations between the constructs. They argue that culture as a variable to constitute groups induce the co-variation of many variables possibly confounding. Recent model of the association between culture and cognitive style appear to complicate the model, proposing multiple and hierarchical influences of cultures on systems of thoughts (Miyamoto 2013). Across three studies, (Konrath, Bushman, and Grove 2009) found that the associations between independence/interdependence self-construal and cognitive style was not clear: it varies across measures of cognitive style (the EFT showed weak correlations). These tenuous results showed more consistency when considering the combined role of independence and interdependence: "*increasing independence (with interdependence subtracted out) leads to increasing narcissism, which in turn leads to increases in analytic and decreases in holistic cognitive-perceptual style*". Thus, it is only the combination of high self-focus and low other-focus which might be related to some variance over the EFT. Two other studies investigated the association of the EFT with other modern individual differences: (Glicksohn, Naftuliev, and Golan-Smooha 2007) found an association between the EFT and the interaction between extraversion and psychoticism, but only for young adult (under 34 Years old). They discuss their results in term of functional and dysfunctional impulsivity. Finally, (Vermigli and Toni 2004) found a relationship between EFT performance time and adult attachment. These two last works seems somehow detached from the rest of the literature in their specific way of processing data (only a specific year range in the first, using performance time in the second) and their argumentation. Taken together, all these recent results provide a very mitigate result about a possible association between FID as measured by the EFT and pro-sociality. None of the conclusions drawn in (Herman A. Witkin and Goodenough 1977) were confirmed in the context of modern psychology.

Another interesting recent line of research about FID based on the EFT focus more directly on variables related to information processing such as attention and working memory. For example, (Guisande et al. 2007) found that FI children have better attentional performance and (Meng et al. 2012) used event-related potentials in adolescents to reveal differences in the "*abilities of FD and FI subjects in mobilizing and/or allocating attentional resources*". Summarizing such findings, (Rittschof 2010) conclude that "*a general caveat indicated by the body of research reviewed here is that FID may be best interpreted as an ability measure that represents executive and visuospatial functioning in working memory*". In a similarly extensive review, (Evans, Richardson, and Waring 2013) conclude that "*there is extensive research that has clearly identified a relationship between FI and working memory*" and then add "*an increased focus on how FI interacts with spatial ability, fluid intelligence, cognitive styles and contextual variables will also be increasingly important in the navigation of the complex and information-rich learning environments of the 21st century*". This association – EFT with working memory related variables – opens the possibility to explore a new nomological framework which might explain correlations with the RFT and others past findings. An interesting line which could link the associations between EFT and working memory (Evans, Richardson, and Waring 2013) and the associations between EFT and fluid intelligence (McKenna 1984) is the

theory proposed by (Fine 1990). In several studies, they evidenced an association between scores on the EFT and sensory discrimination (e.g., in weight or colors). Cited only twice, this line of research has been pursued by no researcher. However, recently two studies evidenced different ways in which sensory discrimination is associated with some measures of intelligence (Troche and Rammsayer 2009)(Melnick et al. 2013). More specifically, (Melnick et al. 2013) build on the fact that given the amount of information our brain need to process, the ability to suppress information is fundamental (gating or facilitation). They evidenced a strong association of "*intelligence with low level sensory suppression of large moving patterns background-like stimuli that are ecologically less relevant*". Finally, (Voelke et al. 2014) found that general discrimination ability, working memory and fluid intelligence were all correlated, with the association between general discrimination ability and fluid intelligence disappearing when controlling by working memory. From this body of work, a sound hypothesis would be that the EFT measures an ability of sensory discrimination or information suppression associated with working memory and intelligence. This ability would play at the visual level and would explain the 20% of shared variance with the RFT. If such analysis is true, the EFT should not consider anymore as related to FID and correlations with possible social related phenomena might stay difficult to explain.

In our view, the RFT based FID is less biased toward ability tests and more in line with original theorizations: the reliance on internal versus external cues as reference. This perspective enables a more straightforward possible explanation of social related phenomena. However, to our knowledge the RFT have not been used as an independent variable in the study of social interactions (always replaced by the more convenient use of the EFT) since (Herman A. Witkin and Goodenough 1977) which make it hard to confirm this view. At the individual level, the RFT have been studied recently in two different line of research which are relevant for the topic of this PhD thesis.

The first line of research associates performance on the RFT with postural control variables. (Kitamura and Matsunaga 1990) first evidenced that FD Japanese woman looking at a dot visual stimuli were less stable as measure by sway path length and variability. Interestingly, these results were not found for the EFT (also measured), confirming that these results could be better accounted by visual-vestibular interactions occurring in the RFT only compared to disembedding abilities of the EFT. Taking extreme individuals on the RFT, (B. Isableu et al. 1997) hypothesized that "*the FD subjects use mainly visual cues for estimating not only their subjective vertical but also their body orientation and stability*". Confirming this hypothesis, they found that FD subjects were less stable and their stability "*required the use of dynamic visual cues, mainly extracted from the vertical frame*". These results were replicated in a subsequent study (Brice Isableu et al. 1998) using the Rod and Disc Test in complement (which assess the impact of dynamic visual field instead of static visual field). These findings revealed how FID impacts not only the perception of vertical, but also body orientation, body position and postural stability. Isableu and colleagues further evidenced differences in the strategies of segmental stabilization in postural control in case of visual disturbance, FD attempting to stabilize their head with the visual frame of reference while FI might have relied on information of vestibular origin (Brice Isableu et al. 2003). In (B. Isableu et al. 2010), the difficulty of the task was varied (normal, tandem or monopodal posture). FD became increasingly more unstable with difficulty, and their preference on rely on the visual frame of reference leaded them to "*greater fixation of the head-trunk articulation*" (en block functioning to reduce the cost of processing proprioceptive inputs). This paper as important implication as it shows that the FID influence depends on the nature of the task, individual differences being more visible in condition requiring adaptations to new references. Similarly, (Davlin-Pater 2010) found no differences in standard standing between FD and FI, but differences in a dynamic balance condition were the surface of the platform could be tilted. In a different line of research, (Scotto Di Cesare et al. 2015) put participants in front of a visual scene and ask them if they felt their body to be tilted at various tilts. Four conditions were tested as a combination of participant body tilt and virtual scene tilt. FD individuals felt a body tilt with a lower threshold of tilt only in the virtual scene tilt. This indicated that in all conditions where individuals had their body tilted, the new dynamical postural cues totally cancelled the effect of visual field dependence evidencing a multisensory reweighting process.

The second line of research is very recent and concerns the sense of agency. (Pfeiffer et al. 2013) used visuo-tactile and visuo-vestibular conflict about the direction of gravity to investigate three aspects of bodily self-consciousness: self-identification, self-location, and the experienced direction of the first-person perspective. In an out-of-body experience, they found that FD individuals did not experience the same direction of the first person perspective: "*FD participants relied more strongly on the gravitational information depicted in the body posture (indicating a dorsal to ventral gravitational acceleration) and adapted the direction of their first-person perspective accordingly (i.e. down-looking). Thus, in this subpopulation, we showed that vision seems to trump vestibular perception for the spatial aspects of bodily self-consciousness*". Although further investigation would be required to generalize such findings, this study extent the importance of FID based on the RFT from perception of the vertical and postural control to bodily self-consciousness: "*our data are important because they reveal that the interpretation of the experienced direction of first-person perspective that humans experience continuously and that is a cornerstone of consciousness studies depends on sensory strategies, or perceptual styles*". In the now classical rubber hand illusion (creates a feeling of owning an artificial limb), (David, Fiori, and Aglioti 2014) evidenced a significant positive correlation between the hand illusion (measured in proprioceptive drift) and the RFT scores. Although these findings are interpreted by authors in terms of the analytic/holistic processing style hypothesis of FID, we would rather interpret it in terms of preferred multisensory integration with FD relying more on external/visual referents. Together, these two recent findings open up a totally new domain of investigation for the understanding of FID.

2.4.5. Conclusion

In summary of the review, it appears that the FID interpretation based on the EFT scores and the analytic/holistic processing style explanation should be dropped to favor the exploration of perceptual styles measured by tests which measure visuo-vestibular interactions such as the RFT. If one is interested in analytic versus holistic processing style, other perhaps less biased measures should be used (Kozhevnikov, Evans, and Kosslyn 2014). Regarding the EFT assessment tool, we identified a promising hypothesis linking it to sensory discrimination, working memory and fluid intelligence. Investigating these associations would clarify the position of the EFT in the past FID literature and perhaps free the concept of FID from sterile debate. Unfortunately, recent investigations of the RFT concentrated on individual variables making hard to draw hypotheses about its usefulness in the interpersonal domain. However, the two recent trends showing the importance of RFT based FID in postural control and bodily self-consciousness evidence the essential role of FID in the way human interact with their environment. Taking together all the limitations of the reviewed literature on FID, it appears hard to propose hypotheses about the possible associations between RFT based FID and modern measures of personality and empathy reviewed in the two previous sections. Given the recent findings on bodily self-consciousness, we might speculate that FID play a more important role in the constitution of agency rather than a specific link with affiliation related variables. Investigating the associations between social perspective taking, agency and FID could clarify this question.

2.5. Associating individual differences and interactional synchrony

In the following of this PhD thesis, we will concentrate our research on the phenomenon of interactional synchrony and the identified individual differences. How these individual differences are linked to interaction synchrony is a difficult question given the lack of detailed investigations. We propose to draw some hypotheses about their associations based on past research but also in a speculative manner (only based on the theory behind it). In addition, we propose to explore not only the "*amount*" of coordination, but also the pattern of the synchrony. We define three type of possible influence:

- Quantity: corresponds to the habitual amount of interactional synchrony, related to the mean synchrony across the interaction.

- Quality: corresponds to the smoothness of the synchronization. In a social interaction, the synchronization is never constant and linear, individuals move in and out the coordination and such variability can be perceived as effortful or fluid. The exact pattern of a smooth synchronization is to be defined.
- Leadership: corresponds the amount of initiative and leading in the interaction. This variable corresponds to the lag in the interaction.

We can now hypothesize associations between these dimensions of interactional synchrony and individual differences:

- Communion : greater quantity
  - hypothesized from the literature: higher interdependent self-construal has been associated with more behavioral matching
- Agency : greater leadership
  - hypothesized from the theory: agency has been associated with extraversion and leadership
- Emotion regulation : greater quality
  - hypothesized from the theory: emotion regulation has been shown to enable the delay of too reactive behaviors to perform more adapted reactions (e.g., empathic concern vs. personal distress)
- Personal distress : weaker quality
  - hypothesized from the theory: personal distress is associated with poorer emotion regulation
- Empathic concern : greater quantity and quality
  - hypothesized from the theory: empathic concern is associated with greater communion and greater emotion regulation
- Perspective taking : greater quantity, greater quality and greater leadership
  - hypothesized from the literature: higher perspective taking has been associated with more behavioral matching
  - hypothesized from the theory: perspective taking is associated with greater communion, greater emotion regulation and greater agency

Figure 33 shows how these hypotheses are integrated into the previously proposed HIDID model.

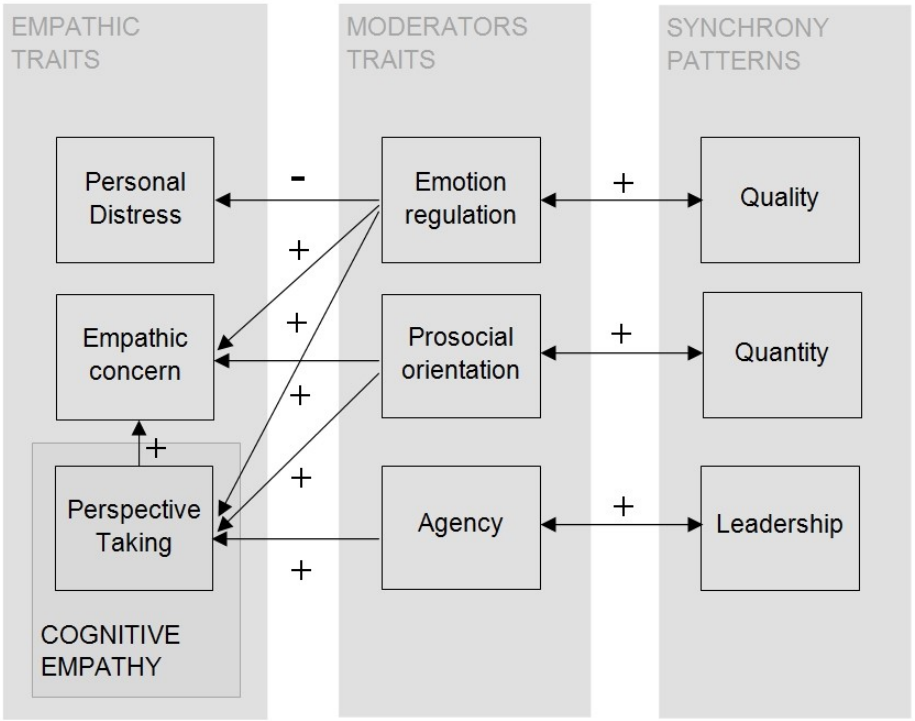


Figure 33: Model HIDID with hypothesized links between synchrony patterns and selected individual differences

3. CONCLUSIONS OF THE STATE OF THE ART

This chapter aimed at providing a comprehensive review of the state of the art about social bodily interaction processes and related individual differences in Computer and Human Sciences.

In Computer Sciences, the domains of IVA and Affective Computing have always considered the importance of individual differences in order to personalize the user experience. However, the review revealed an extensive focus on the Five Factor model of personality leaving aside a large variety of individual differences. The fact that the FFM is descriptive in nature has limited the development of sound hypotheses regarding the associations between individual differences and interpersonal processes, results interpretations being most of the time based on heuristic reasoning or interpretations of questionnaire items. Another limitation of this literature is the limited presence of works proposing bodily mutual adjustments such as synchrony: some projects proposed the heuristic modeling of mimicry (body postures) or the data-driven modeling of head backchannels. Overall, the field appears to move toward more data-driven approaches to social phenomena as a response to weak theoretical propositions available in Human Sciences. We agree with the fact that data-driven methods provide a promising root toward more realistic social interactive models. But we advocate that data-driven methodologies are never totally theory free (often they have implicit assumptions about social cognition) and that a deeper investigation of advances in Human Sciences would enable to better orient the development of future models. Motivated by these limitations, we undertook a review of the similar concepts in the Human Sciences literature.

Regarding interpersonal processes, we identified two spontaneous low level bodily interpersonal processes: behavior matching and interactional synchrony. Although they correspond to two different lines of research with various theoretical influences, their moderators have been found to be very similar. Researchers in Human Sciences seem to move toward a more systematic use of the concept of synchrony instead of mimicry (behavior matching). The concept of synchrony has the advantage of encompassing the phenomenon of mimicry, being dynamic in nature and inducing a set of quantitative methodologies (in opposition to behavior matching which has been weakly operationally defined). Associated with this increased interest in the phenomenon of synchrony is a forthcoming radical shift in the understanding of social cognition: the dynamic two bodies' dance of social interaction is re-considered at the heart of all social phenomena. As a consequence, this research movement advocates the design of two person experiments instead of social stimulus-response paradigms such as extensively used in empathy studies. In this context, more interest is put on dyadic corpora collection (to capture the essence of the interaction) and the design of interactive virtual humans based on real life data (to re-enact the interaction in a more controlled way). This methodological shift is a great opportunity for strong interdisciplinary projects where accumulated expertise in Virtual Human modeling from Computer Sciences could intertwine with experimental interests and theorizations from Human Sciences.

We also identified a set of individual differences which has been linked to behavior matching or interactional synchrony, among which the FFM framework was absent. These individual differences were systematically associated with the "*amount*" of interpersonal coordination without proposition considering possible different "*pattern*" of coordination. Based on these identified individual differences – empathy dispositions, pro-social orientation and cognitive style –, we undertook a review of the Human Science literature to better understand their respective nomological framework and how and why they contribute to social coordination. Together, these three lines of research enabled us to propose an working model of hypotheses (HIDID) about their respective associations. We also proposed some speculative hypotheses about how these identified individual differences would influence the coordination process. This model will guide our interpretation throughout this PhD thesis.

CHAPTER 3

Individual differences and bodily interaction

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The state of the art presented in Chapter 2 enabled us to identify individual differences related to bodily interpersonal processes, to propose an model of working hypotheses with these individual differences and their respective associations, and to draw some more speculative hypotheses about how these individual differences might be related to bodily synchronization patterns.

Before going into the analysis of social interactions to explore the influence of individual differences, a first step is to confirm the validity of the individual differences part of our hypothesized model (HIDID). Knowing how the identified individual differences are inter-related is of particular importance to understand how interpersonal behaviors are coherently organized. The design of virtual humans requires to propose an integrated unified model of behaviors and personality has been used to provide such coherence. However, the almost exclusive use of the Five Factor Model of personality appeared of limited value in the interpersonal domain. The nomological framework constituted by the identified individual differences is interpersonal-oriented with evidenced links to interactive bodily behaviors. Confirming its validity could provide an interesting alternative to the FFM for the design of bodily interactive virtual humans.

To our knowledge, no study tested together the various identified individual differences from empathy, emotion regulation and pro-social orientation. As mentioned in the state of the art, (Grynberg et al. 2010) presented a factor analysis of alexithymia subscales and empathy subscales without clearly proposing a theoretical model articulating them. Complementarily, (Konrath et al. 2011) conducted a regression analysis to predict alexithymia subscales from self-construal subscales. None of these studies provide indications about how to integrate these three constructs together.

The purpose of this chapter is to investigate the validity of our proposed hypothesized model using traditional methods in personality psychology and contribute to this field. When studying the articulation between assessments tools of individuals differences, one requirement is the use of validated assessment tools which include various types of validity such as test-retest stability (how the test is stable over time) or criterion validity (how the test covaries with some well-respected outside measure(s) of the same construct). A questionnaire validated in one language should be re-validated in the new language before being used in this later. Another common practice is the collection of data from a large sample population. In addition to increasing the reliability of the findings, some classical analysis methods inherently require a large amount of data in order to robustly estimate a model. This is the case for confirmatory factorial analysis – which aims at testing if observed variables load on hypothesized latent factors – and structural equation modeling – which aims at estimating if the hypothesized path model between observed and latent is valid – for which a classic rule a thumb specify that one needs at least 20 observations per variables in the model for robust estimation (Brown 2006)(Kline 2011).

1. METHODOLOGICAL CONSIDERATIONS

1.1. Individual differences assessment tools

In order to estimate the validity of the model drawn in the state of the art, we have to use assessment tools which measure each of the subcomponents of the model. For each of the variables in our proposed model, we have to choose which existing French-validated questionnaire will be used:

- Empathy: the Interpersonal Reactivity Index – IRI – (Davis 1983) is the most widely used questionnaire to assess empathy as a multidimensional construct, a requirement for our model. It has been validated recently in French by (Gilet et al. 2013):

- 28-item questionnaire which assesses individuals' empathic trait across four dimensions: Empathic Concern (EC), Perspective Taking (PT), Personal Distress (PD), and Fantasy (F). Across the questionnaire, participants are asked to indicate how much each item resembles them on a 7-point Likert scale ranging from 1, "*does no describe me well*", to 7, "*describes me very well*".

- Emotion regulation: the Toronto Alexithymia Scale – TAS20 – (Bagby, Parker, and Taylor 1994) is the most widely used questionnaire to assess alexithymia, a construct associated with emotion regulation. It has been validated in French by (Loas et al. 1997):
  - 20 item questionnaire where subjects are required to indicate their level of agreement with each item on a 5-point Likert scale ranging from 1, "*does not suit me at all*", to 7, "*suits me perfectly*". The questionnaires comprises of a three-factor structure, factors labelled Difficulties in Identifying Feelings (DIF), Difficulties in Describing Feelings to others (DDF), and Externally Oriented Thinking (EOT), the three subscales being added to form a global factor (ALEX). The DIF and DDF are suggested to reflect affect-related alexithymia, whilst EOT is rather cognition-related (Grynberg et al. 2010).
- Pro-social orientation: to our knowledge, no questionnaire inherited from the two polarities models of personality is available in a validated French version. Thus, we decided to choose a validated questionnaire in English and validate it in French. the Self-Construal Scale – SCS – (Singelis 1994) has the advantage to be the only measure which has been associated with behavior matching. Also, a series of recent study investigate its associations with the two questionnaires (IRI and TAS20). Finally, we found other researcher in France eager to validate it with us (see credit section). In its original form, the SCS is a:
  - 24-item scale which relates an individual's Independent (IND), and Interdependent (INT) self-construals. Participants are instructed to indicate their agreement with each statement on a 7-point Likert scale ranging from 1, "*completely disagree*", to 7, "*completely agree*".
- Field independence/dependence: FID is a cognitive style assessed via a perceptual test which does not require any translation apart from the instruction (which does not require any validation). As discussed in the state of the art, two tests exist – the Embedded Figure Test (EFT) and the Rod and Frame Test (RFT) – which do not measure the same construct (FID). In order to test this hypothesis, both will be used.
  - Embedded Figure Test: participants have to identify a simple figure within a more complex figure such that "*the latter create a gestalt within which the part is hidden*" (H. A. Witkin and Goodenough 1981)(Figure 33). In this thesis, EFT designed for groups is used. A group of participants have to perform the whole test within a given time. The test is composed of 50 figures to identify. The score of a participant represents the number of good response to the test.
  - Rod and Frame Test: participants have to orient a rod to the word vertical by rotating it. The participant's head is within a rectangular optical box hiding every visual reference to the word vertical apart from of the square frame of the rectangular optical box (Figure 33). In the test, the square frame is tilted (e.g., 18°) to provide on erroneous visual information. To adjust the rod to the word vertical, the participant should rely on his/her bodily sensations (vestibular and proprioceptive information) without considering the square frame (participants are not explicitly instructed to use this strategy). The test consists of 8 trials with starting values of the rod (i.e., 18° and -18°) as well as orientations of the optical box (i.e., 18° and -18°) that are counter balanced. For one trial, the score is computed using the method proposed in (Nyborg 1974). The participant score is averaged over the 8 trials.

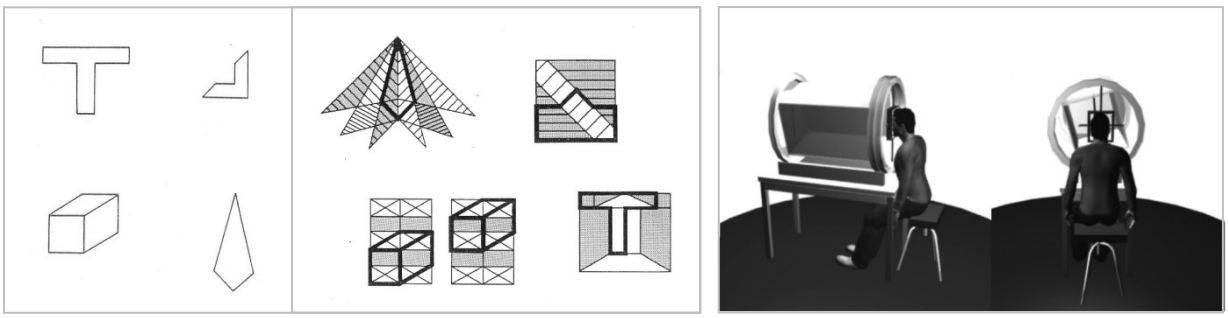

Figure 33: a) Example of figures to find in the EFT b) RFT apparatus from (Isableu et al. 2008)

In addition, two measures of Narcissism were collected. Their use is described in the second analysis of this chapter:

- Grandiose Narcissism: the Narcissistic Personality Inventory Scale – NPI – (Raskin and Hall 1981) is a measure of the Grandiose aspect of Narcissism (Raskin and Terry 1988). This is the aspect of narcissism closest to the common sense term: enhance confidence and sense of superiority, being aggressive against negative feedbacks. It has been validated recently by (Gibas et al., in prep):
    - 21-item scale which assesses the grandiose dimension of narcissism (GN). Participants are instructed to indicate their choice among two possible answers corresponding to a statement, one being high in narcissism and the other being low.
- Vulnerable Narcissism: the HyperSensitive Narcissism Scale – HSNS – is a measure of the Vulnerable aspect of Narcissism associated with a fear of rejection: individuals rating high on this scale feel anxious when not treated as superior. It has been validated recently by (Gibas et al., in prep):
    - 9-item scale which assesses the vulnerable dimension of narcissism (VN). As in the TAS-Fr, participants' are asked to rate each item on a 5-point Likert scale.

Based on this selection, this chapter is organized in three parts. First, the validation of the SCS in French is presented. The second section presents the investigation of the proposed model based on the subscales from the three selected questionnaires – IRI, TAS20, SCS –. And lastly we analyse the articulation of FID related measures within this framework.

1.2. Model evaluation standards

In this chapter, we will use both Confirmatory Factorial Analysis (CFA) and Path Analysis (PA) in order to first validate the Self-Construal Scale and then explore the validity of our integrative model. In both cases, the resulting model should be evaluated according to its goodness of fit: how well the estimated model explains the observed covariance. Several types of statistical tests and indicators have been proposed in the literature but before detailing them, it is important to acknowledge that no true model exists. As putted by (Kline 2011), "*a statistical model is an approximation tool that helps researchers to structure their thinking (i.e., generate good ideas) in order to make sense of a phenomenon of interest*". This statement is even sounder for CFA and PA which are confirmatory methods requiring strong a priori hypotheses: "*one of the most important aspects of model evaluation occurs prior to the actual statistical analysis – that is, providing a compelling rationale that the model is meaningful and useful on the basis of prior research evidence and theory*" (Brown 2006). Following this rationale, it appears essential to always compare a proposed model against potential alternatives theoretically sound.

For the choice of statistical standards in model evaluation, we refer to guidelines provided in both (Brown 2006) (Kline 2011). Three main points might be analyzed when assessing fit acceptability:

- Overall goodness of fit: assess the model fit in a global manner, providing no information about local discrepancy. Within this point, three class of indicators exist and one indicator from each class should be reported to provide a more complete description of the model fit:
    - Absolute fit indices: indicates the difference between observed and expected covariance matrices. The most classical indicator is the chi^2 (chi-square) and is a test of "*badness*" of fit indicator: it tests the prediction that there are no discrepancies between observed and expected covariance. A model passes the test if the chi^2 is not significant. The Standardized Root Mean Square Residuals (SRMR) is the average discrepancy between the correlations observed in the input matrix and the correlations predicted by the model, with values below 0.08 considered "*reasonably good*".
    - Parsimony fit indices: provide indicators which penalize the complexity of the model (i.e., number of freely estimated parameters). The Root Mean Square Error of Approximation (RMSEA) is the most widely used indicator, with values below 0.06 considered "*reasonably good*"
    - Comparative fit indices: also called incremental fit indices, evaluate the model against a "*null model*" in which the covariances among all input indicators are fixed to zero. The Comparative Fit Index (CFI) is often reported, with values above 0.95 considered "*reasonably good*".
- Localized areas of strain: assess if some relationships in the observed data have not been reproduced adequately. A common approach is to look at the residual variance-covariance matrix which reflects the difference between the sample and model implied matrices. Correlation residual values above 0.1 indicate local discrepancy.
- Interpretability, size and statistical significance of the model's parameter estimates. This last step of evaluation of the model aims at verifying that in addition to goodness of fit, the size and sign of path estimates correspond to what the one hypothesized.

In this PhD thesis, for both CFA and PA we will report chi^2, SRMR, RMSEA and CFI in order to assess overall fit. Then the two last steps will be done only for PA as the CFA will be used in the context of a questionnaire validation where no attention is given to the local structure within sub-factors.

2. FRENCH TRANSLATION AND VALIDATION OF THE SELF CONSTRUAL SCALE

The self-construals dimensions have proven their value in social psychology research, offering opportunities to ascertain the impact of self-concepts on various aspects of cognition, motivation, and social behaviours (Cross, Hardin, and Gercek-Swing 2010). Such researches have been conducted at both within- and between-culture levels, the latter underlining the necessity for validated inventories in languages other than English.

The 24-item Self-Construal Scale (SCS) was developed by (Singelis 1994) and has since been the most widely used form of self-construal scale although concurrent scales, varying in both number of items and factors, have been proposed (Cross, Hardin, and Gercek-Swing 2010). In an attempt to ascertain culture-dependent individual differences, the SCS has been translated into a number of different languages, including Japanese (Sato and Cameron 1999), Chinese (Aaker and Schmitt 2001), Singaporean, Hebrew and Israel Arabic (Kurman 2001), Thai and Taiwanese (Neff, Pisitsungkagarn, and Hsieh 2008), Korean (Sung, Choi, and Tinkham 2012), Greek (Nezlek, Kafetsios, and Smith 2008), Spanish and Norwegian (Kolstad and Horpestad 2009). French language versions of the scale have been used in recent studies (Bry, Follenfant, and Meyer 2008a)(Fernandez, Paez, and Gonzalez 2005)(Conte and Bonnefoy 2009a), showing a clear interest from the French-speaking community in the Self Construal construct. However, to date no formal validation of the French version of the scale has been conducted.

Whilst the inventory exists in many languages, the scale has shown recurrent weaknesses across cultures in its psychometrics properties. Inter-item reliabilities of the two scales – self-independence and self-interdependence – are often below an adequate level with Cronbach's alpha ranging from 0.53 to 0.90 (Cross, Hardin, and Gercek-Swing 2010). (Levine et al. 2003) call into question the convergent validity of self-construal scales, with faulty scale validation potentially to blame. Furthermore, considering self-construal as a two-factor construct may be over-simplistic (Gudykunst et al. 1996)(Hardin, Leong, and Bhagwat 2004)(Kim et al. 1996)(Matsumoto 1999). Finally, (Bresnahan et al. 2005) also suggest that the conceptual justifications provided for the inclusion of certain items in the SCS is unclear. One factor contributing to the scale inconsistencies is the lake of systematic translation methodology (Vallerand 1989). Several analyses can be done to assess various aspect of the questionnaire validity such as:

- Back translation: refers to the process of a translation in two steps: translating from the first language to the second and translating back to the first language by other translator to assess the gap with the original items
- Face validity: refers to how the test appears coherent to expert, when analyzing questionnaire items
- Internal validity: refers to how the internal structure of the test fit the data (structure validity) and how each subscale is coherent (internal consistency). During this step, questionnaire items are deleted if not well suited to the model
- Criterion validity: refers to how the test covary with some well-respected outside measure(s) of the same construct
- Discriminant validity: refers to how the test diverge from some well-respected outside measure(s) of an opposite construct
- Test-retest stability: how the test is stable over time, most of the time between two consecutive time point with three months interval

Table 8 reports 9 studies which include a translation process of the Self Construal Scale: while most include a back-translation step, most do not go further in the validation of the scale. When the latent structure is explored, criteria for item exclusion (if any) and factor extraction methods appear to vary.

Studies	Questionnaire	Languages	Back-Tran.	Items Sel.	Items per scales	Cronbach's α
(Sato and Cameron 1999)	Singelis (1994)	Japanese	Yes	No	Int: 12; Ind: 12	Int =.75; Ind=.67
(Aaker and Schmitt 2001)	Singelis (1994)	Chinese	Yes	Yes[1]	Int: 11; Ind: 9	Int =.90; Ind=.78
(Kurman 2001)	Singelis (1994)	Singaporean	Yes	Yes[2]	Int: 5; Ind: 11	Int =.56; Ind=.60
		Israeli Druze	Yes	Yes[2]	Int: 5; Ind: 11	Int =.56; Ind=.61
		Israeli Jews	Yes	Yes[2]	Int: 5; Ind: 11	Int =.57; Ind=.64
(Polyorat, Alden, and Alden 2005)	Singelis (1994)	Thai	Yes	No	Int: 12; Ind: 12	Int =.71; Ind=.61
(Neff, Pisitsungkagarn, and Hsieh 2008)	Singelis (1994)	Thai	Yes	No	Int: 12; Ind: 12	Int =.77; Ind=.66
		Taiwanese	Yes	No	Inr: 12; Ind: 12	Int =.69; Ind=.62
(Nezlek, Kafetsios, and Smith 2008)	Singelis (1994)	Greek	Yes	No	Int: 12; Ind: 12	Int =.56; Ind=.72
(Kolstad and Horpestad 2009)	Singelis (1994)	Spanish	No	No	Int: 12; Ind: 12	Int =.57; Ind=.67
		Norwegian	No	No	Int: 12; Ind: 12	Int =.64; Ind=.69
(Christopher et al. 2011)	Hardin (2004)	Thai	Yes	No	Int: 14; Ind: 18	Int =.79; Ind=.78
		American	Yes	No	Int: 14; Ind: 18	Int =.76; Ind=.72
(Sung, Choi, and Tinkham 2012)	Singelis (1994)	Korean	Yes	No	Int: 12; Ind: 12	Int=.72; Ind=.70

[1]: keep items with "item-to-factor" correlation <.40

[2]: remove items until reaching a correct Cronbach's alpha

Table 8: Studies including a translation process of the Self Construal Scale

The aim of the present study is thus to present the steps that we followed in order to validate a French-translated version of (Singelis 1994) 24-item Self-Construal Scale. We methodically conducted two studies in an attempt to maximize both the conceptual and statistical validity of our inventory so as to ensure the replicability of our chosen procedure. Following guidelines set out by (Vallerand 1989), study 1 pertains to the translation of the inventory, item face-validity checks, and factor analyses. Whilst we will assess fit of the initial two-factor structure upon which the original SCS was constructed (Singelis 1994), it appears necessary to remain open to alternative structures, factors, and number of items. Study 2 aims to assess the inventory's test-retest stability, as well as its criterion-related validity based on correlations with the Five Factor model of personality traits (Costa and McCrae 1992).

2.1. Translation of the scale

In compliance with the guidelines put forward by (Vallerand 1989) when translating a personality inventory, the 24 original items of (Singelis 1994) Self-Construal Scale were translated from English to French, and back to English. The translation from English to French was performed by two French individuals. Translation back to English was then achieved by three other bilingual individuals. Original and back-translated items were then compared, with appropriate amendments applied where deemed necessary. Only one item showed ambiguity in the translation - *I feel comfortable using someone's first name soon after I meet them, even when they are much older than I am* – as the use of the first name is highly different across cultures. We changed the reference to the first name to the difference in French between "*tu*" (addressing somebody using the familiar form) and "*vous*" (addressing somebody using the formal form). The subsequently obtained French items were then submitted to a sample (n = 40) of French-speaking adults (23 female, 17 male) with an average age of 30.60 (*SD* = 7.09). These adults who were asked to rate the clarity of the items on a 6-point Likert scale ranging from 1 "*not at all clear*" to 6 "*perfectly clear*".

ID	Items
1	Être unique et différent des autres de diverses manières me plait. *[I enjoy being unique and different from others in many respects.]*
2	Je peux tutoyer facilement quelqu'un que je viens juste de rencontrer, même s'il est bien plus âgé que moi. *[I feel comfortable using someone's first name soon after I meet them, even when they are much older than I am.]*
3	Je préfère dire « Non » directement, plutôt que de discuter longtemps d'une question et d'être mal compris(e). *[I'd rather say "No" directly, than risk being misunderstood.]*
4	Avoir beaucoup d'imagination est important pour moi. *[Having a lively imagination is important to me.]*
5	Je préfère être direct(e) et sans équivoque lorsqu'il s'agit de personnes que je viens de rencontrer. *[I prefer to be direct and forthright when dealing with people I've just met.]*
6	Je suis à l'aise lorsqu'on me fait des louanges ou qu'on me félicite. *[I am comfortable with being singled out for praise or rewards].*
7	Prendre la parole en classe (ou pendant une réunion) n'est pas un problème pour moi. *[Speaking up during a class is not a problem for me.]*
8	Je me conduis de la même façon, peu importe avec qui je suis. *[I act the same way no matter who I am with.]*
9	Pour moi, être en bonne santé passe avant tout. *[I value being in good health above everything.]*
10	Être en mesure de prendre soin de moi est une préoccupation essentielle pour moi. *[Being able to take care of myself is a primary concern for me.]*
11	Ma propre identité, indépendamment des autres, est importante pour moi. *[My personal identity independent of others, is very important to me.]*
12	Je me conduis de la même façon à la maison qu'à l'école (ou au travail). *[I am the same person at home that I am at school.]*
13	Même si je suis fortement en désaccord avec les membres d'un groupe, j'évite d'argumenter. *[Even when I strongly disagree with group members, I avoid an argument.]*
14	J'ai du respect pour les figures d'autorité avec lesquelles j'interagis. *[I have respect for the authority figures with whom I interact.]*
15	Je respecte les gens qui sont modestes. *[I respect people who are modest about themselves.]*

16	Je sacrifierais mon propre intérêt pour le bénéfice du groupe auquel j'appartiens. *[I will sacrifice my self-interest for the benefit of the group I am in.]*
17	Je devrais prendre en considération les conseils de mes parents lorsque j'établis mon projet professionnel, mes plans de carrière (ou *[I should take into consideration my parents' advice when making education/career plans.]*
18	Si mon frère ou ma soeur échoue, je me sens responsable. *[If my brother or sister fails, I feel responsible.]*
19	J'ai souvent le sentiment que mes relations avec les autres sont plus importantes que mes réussites personnelles. *[I often have the feeling that my relationships with others are more important than my own accomplishments.]*
20	J'offrirais ma place assise dans un bus (métro, train…) à mon enseignant (ou mon patron). *[I would offer my seat in a bus to my professor.]*
21	Mon bonheur dépend de celui de mon entourage. *[My happiness depends on the happiness of those around me.]*
22	Je resterais dans un groupe s'ils ont besoin de moi, même si je ne suis pas heureux (se) avec ce groupe. *[I will stay in a group if they need me, even when I'm not happy with the group.]*
23	Il est important pour moi de respecter les décisions prises par le groupe. *[It is important to me to respect decisions made by the group.]*
24	Il est important pour moi de maintenir une harmonie à l'intérieur de mon groupe. *[It is important for me to maintain harmony within my group.]*

Table 9: List of the 24 items from the Singelis SCS (1994) translated in French and subscales to which they belong based on Singelis' (1994) original structure.

In order to ascertain item clarity, item-specific means and standard deviations were computed in order to reveal recurrently problematic items. Items revealing clarity means approaching or below 3.5 or large standard deviation values would thus be amended as necessary. None of the items had to be amended. The final translated list of items is presented in Table 9.

2.2. Latent structure and internal validity

2.2.1. Data collection

For internal consistency and latent structure analyses, a total of 567 French-speaking students (340 female, 227 male) with an average age of 20.36 (*SD* = 6.63) were recruited on a voluntary basis. A first group of 231 participants (51 female, 180 male) with an average age of 19.34 (*SD* = 1.39) completed the questionnaire in pen-and-paper form, whilst the remaining 336 subjects (289 female, 47 male) with an average age of 21.06 (*SD* = 10.24) filled in an online version of the questionnaire. Participants were instructed to indicate their level of agreement with each of the 24 items on a 7-point Likert scale ranging from 1 "*Strongly Disagree*" to 7 "*Strongly Agree*".

2.2.2. Data analysis

Both exploratory and confirmatory factor analyses were performed in order to assess the latent structure of our newly-translated French Self-Construal Scale (SCS-Fr). Exploration of our data set revealed severe deviations from multivariate normality (cf. mahalanobis distance test). Indeed, the largest value is 92.50, as compared to a critical value of 36.42. Exploratory factor analyses, conducted using SPSS version 20 for Windows, used Principal Factor analysis (PF) method of estimation and promax oblique rotation as recommended when multivariate normality is severely violated (Osborne 2008). We preferred this estimation method to the Principal Component (PC) approach used initially by Singelis (1994) as it directly aims "*to reveal any latent variables that cause the manifest variables to covary*" (Osborne 2008) by taking into account only the common variance of our variables. Item-specific contributions were also assessed based on their loadings on emergent factors. To our knowledge, no guidelines are available in the literature regarding the threshold to be used for item deletion. While using PC estimation method, (Singelis 1994) initially used a threshold of 0.35. As our estimation method (PF) provides lower loadings on estimated factors, we chose a lower threshold of 0.25. Thus, items loading below .25 on emergent factors were

considered too unique (i.e. insufficient shared variance) and removed from further analyses. Confirmatory factor analyses were conducted using LISREL version 9.1 for Windows, and used Diagonally Weighted Least Squares (DWLS) method of estimation and promax oblique rotation. As PF when conducting exploratory analyses, DWLS estimation method has been shown robust with multivariate non-normal ordinal data, reducing confirmatory factor analysis parameter estimate error (Brown 2006). Model fit was assessed using conventional goodness-of-fit criteria (Brown 2006). Internal consistencies of the subsequently obtained factors were tested by computing Cronbach alphas.

2.2.3. Results

A first confirmatory factor analysis (CFA) was used to fit the data to Singelis' (1994) two factor solution. This structure suggests that 12 items load onto an "*Independent*" self-construal factor, whilst the other 12 fit onto an "*Interdependent*" self-construal factor. Model fit fell short of satisfactory standards based on conventional goodness-of-fit criteria, with values of: Satorra-Bentler chi^2 (df = 251, N = 567) = 795.53, p < .001; Standardized Root Mean Square residual (SRMR) = .068; Root Mean Square Error of Approximation (RMSEA) = 0.062 and Comparative Fit Index (CFI) = .69; and. Cronbach alphas for the "*Independent*" and "*Interdependent*" factors were respectively 0.54 and 0.59. Although the model show acceptable parsimonious fit, absolute and comparative fit indicators are far from good.

Exploratory factor analyses (EFA) were subsequently used in order to test item-specific contributions to the two-factor solution. Based hereupon, items that did not load at >.25 on either factors were discarded from further analyses, as they were not considered to contribute to the inventory. Items 2, 3, 6, 7, 8, 12, 13, 18 and 20 were removed with this EFA. Following this step, all items loaded higher than 0.25 on one of the two factors. Using the remaining 15 items, Singelis' (1994) two-factor solution was again tested using CFA, with items 1, 4, 5, 9, 10 and 11 loading on the "*Independent*" self-construal factor (Cronbach alpha = 0.52) and items 14, 15, 16, 17, 19, 21, 22, 23 and 24 loading on the "*Interdependent*" self-construal factor (Cronbach alpha = 0.66). Fit still fell short of meeting conventional goodness-of-fit standards, with: Satorra-Bentler chi^2 (df = 89, N = 567) = 310.39, p < .001; SRMR = .073; RMSEA = 0.066 and CFI = .87; However, a chi-square difference test did reveal that item removal significantly improved absolute model fit, with delta chi^2 (delta df = 162, N = 567) = 482.99, p < .001, providing support to the upstream removal of problematic items. This was confirmed by the increased in SRMR and CFI.

In a final attempt to improve model fit, and based on suggestions that more elaborate latent structures may best account for the SCS, a new EFA was carried out on the remaining 15 items. The best choice of number of factors retained was made based on the scree test rules (Cattell 1966).

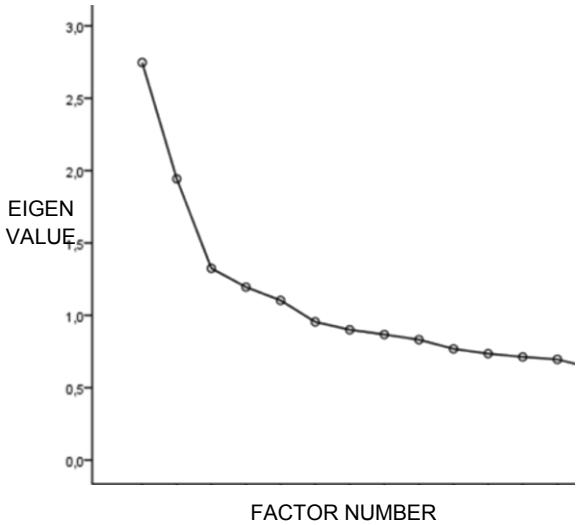

Figure 34: Scree plot resulting from an EFA on the 17 selected items

The scree plot suggested that a 3-factor solution may be most appropriate (see Figure 34). Subsequent factor rotation yielded a first factor with items 1, 4, 5, 10, and 11, a second factor consisting of items 9, 14, 15, 17, 23 and 24, and a third and final factor comprising items 16, 19, 21 and 22. Whilst the first factors appear to relate to Singelis' (1994) independent self-construal, the second and third factors relate to two interdependent facet of self-construal. As item 9 is suggested to belong to the former but rather fitted incoherently on the

latter, it was removed from further analyses without consequence on the factor structure.

Improvement of fit was assessed by conducting a third and final CFA based on the remaining 16 items using the 3-factor solution suggested by the EFA. By conventional standards, model fit was acceptable, with: Satorra-Bentler chi^2 (df = 74, N = 567) = 160.69, p < .001; SRMR = .051; RMSEA = 0.046 and CFI = .92. Whilst the Satorra-Bentler chi^2 remains significant, Ullman (1996) suggests that if it approaches 2 when divided by its associated degrees of freedom, model fit may be considered satisfactory. A chi square difference test revealed that the 3-factor solution represented a significant improvement on Singelis' (1994) two factor solution, with delta chi^2 (delta df = 15, N = 567) = 149.70, p < .001. SRMR, RMSEA and CFI all meet goodness of fit standards. In terms of internal consistencies, Factor 1 (1, 4, 5, 10, and 11) yielded an alpha value of .48, whilst those for factors 2 (items 14, 15, 17, 23 and 24) and 3 (items 16, 19, 21 and 22) were of .56 and .54, respectively.

2.2.4. Discussion

The aims of this first study were to attempt to replicate the initial two-factor structure of the Singelis' SCS (1994) and to uncover the best-fitting latent structure for the newly-translated French SCS (SCS-Fr). Combining both confirmatory and exploratory approaches, we discarded 9 items to replicate at best the initial two-factor structure, resulting in a 15 items version (9 items for the "*Interdependent*" scale, 6 items for the "*Independent*" scale). Encouraged by poor model-fit parameters and internal consistencies, further analyses revealed that a three-factor structure based on 14 items is the most appropriate for the French version of the scale. Further to this, whilst the first factor exclusively comprised items relation to an independent self-construal, the two remaining factors comprise items from Singelis' (1994) "*Interdependent*" self-construal factor.

Our three-factor solution is reminiscent of previous work conducted both on self-construals in general as well as on the SCS. Indeed, in their study of culture- and gender-related differences in self-construals, (Kashima et al. 1995) suggest that three construals of the self – namely independent, relational, and collective – may be more appropriate and information-rich than the traditional two-factor construct. In other words, the "*Interdependent*" factor suggested by Singelis (1994) may subsume two distinct factors, "*Relational*" and "*Collective*". Further to this, factor analyses using a 30-item version of the SCS appear to confirm the existence of two factors relating to interdependent self-construal, namely "*Relational*" and "*Maintaining Harmony*" (Hardin, Leong, and Bhagwat 2004). Based upon these proposed structures, and considering the content of our remaining items, we believe that whilst factor 1 relates to "*Independence*" (*I,* 5 items), factors 2 and 3, interdependent in nature, relate to "*Maintaining Harmony*" (*MH,* 5 items) and "*Relational*" (*R,* 4 items). Whilst conceptually reminiscent of Kashima et al.'s (1995) "*Collective*" factor, we contend that the heading "*Maintaining Harmony*" better disambiguates the factor and its items.

To go back over the criticism brought on by the original SCS (Levine et al. 2003)(Matsumoto 1999), the newly-translated SCS-Fr is characterized by low internal consistencies whether we consider its two or its three factors structure. Although model fit significantly improved, the detailed and methodical approach we undertook to explore the latent structure did not reveal a much better solution. The next part of the present study focuses on the three-factor structure as it is the best fitting structure with a good interpretability level.

2.3. Criterion-Related Validity and Test-Retest Stability

Following internal validation of the translated inventory, (Vallerand 1989) recommends conducting criterion-related validity and test-retest stability tests on separate samples. Guidelines regarding test-retest stability may be comfortably followed. Ascertaining criterion-related validity of the SCS-Fr may, however, not be as straightforward. Indeed,

(Bresnahan et al. 2005) show that different measures of self-construal lack convergent validity between themselves, yielding correlation values no more robust or reliable than those entertained with unrelated constructs. These observations in mind, we contend that investigating the correlational pattern between the SCS-Fr and Five Factor model of personality may provide initial support for our inventory's criterion-related validity, essentially that which pertains to the two interdependence factors, *MH* and *R*.

The Five Factor model of personality is a widely used personality taxonomy which characterizes an individual's personality across five broad traits, namely Extraversion (*E*), Agreeableness (*A*), Conscientiousness (*C*), Neuroticism (*N*), and Openness (*O*) (Plaisant, Courtois, Réveillère, Mendelsohn, & John, 2010). In their validation of the Relational-Interdependent Self-Construal scale (RISC), (Cross, Bacon, and Morris 2000a) contend that the measures of Agreeableness and Extraversion, the most prosocial of the Five Factor model traits, should positively correlate with measures of interdependent self-construal. To the best of our knowledge, no previous studies have studied the "*Independent*" scale from the Singelis SCS and the Five Factor model traits together within a Western culture making it hard to construct assumptions about potential correlations. However, based on theoretical descriptions of the independent self by (Hazel R. Markus and Kitayama 1991) as "*expressing one's unique configuration of needs, rights and capacities*" (p.226), one might expect a positive correlation with the Openness trait which captures the individual's sense of originality and creativity. Studies on individualism/collectivism also support this assumption, whereby "*openness emerges more readily in individualist cultures, particularly among student samples that tend to be idiocentric, than in collectivist cultures*" (Triandis and Suh 2002).

2.3.1. Data collection

Two separate samples were recruited in order to assess the newly-translated SCS-Fr's (1) test-retest reliability and (2) the premises of criterion-related validity. The test-retest sample comprised 66 young French-speaking adults (30 female, 36 male) with an average age of 19.21 years (SD = 1.67). Subjects filled out the SCS-Fr at two different time-points, with a test-time interval of 3 months. In order to further put the inventory's stability to the test, order of items was randomised between test-times.

Criterion-related validity was assessed thanks to a sample of 68 young French-speaking adults (39 females, 29 males) with an average age of 29.53 years (SD = 7.39). Subjects completed online versions of the SCS-Fr and the validated French version of BFI (Plaisant et al. 2010), a 45-item Likert-scale inventory where individuals' personality is rated across the Big Five personality traits.

2.3.2. Data analysis

Test-retest stability was assessed using between-time bivariate correlations and Wilcoxon signed-rank test. Criterion-related validity was ascertained with bivariate correlations computed between SCS-Fr and BFI-Fr subscales. All analyses were carried out with SPSS version 20.0 for Windows.

2.3.3. Results

As can be seen in Table 2, all three *I*, *MH*, and *R* subscales at test-time 1 were moderately correlated with themselves at test-time 2, with respective r-values of .35, .30, and .53. Further to this, Wilcoxon signed-rank tests revealed no significant differences in the mean scores for either *I* or *R* subscales between test-times (Table 10). A significant difference was, however, found between the means of *MH* subscale at times 1 and 2. However, the significance of the between-time mean difference of 1.28 may be due to its relatively narrow dispersion (Table 10), and therefore not be symptomatic of the inventory's instability across time.

The bivariate correlations between SCS-Fr subscales and BFI-Fr subscales are summarized in Table 11. SCS-Fr's *I* subscale only correlates significantly with BFI-Fr *Openness* (r = .28, p < .05), whilst both *MH* and *R* subscales correlate significantly and positively with BFI-Fr *Agreeableness*, with r = .60 (p < .005) and r = .25 (p < .05), respectively. Finally, the SCS-Fr *R* subscale and BFI-Fr *Neuroticism* are significantly and positively correlated (r = .28, p < .05).

		Test		Retest		Test-retest	
		M	SD	M	SD	r	Z
SCS-Fr	I	30.30	5.072	29.53	4.152	.349**	-1.427
	MH	27.55	3.411	26.27	3.381	.299*	-2.762*
	R	21.76	4.455	21.17	3.723	.527**	-1.151

Note. * = significant at p < .05; ** = significant at p < .005. For SCS-Fr: *I* = independent self-construal; *MH* = maintain harmony self-construal; *R* = relational harmony self-construal.

Table 10: Bivariate correlations and Wilcoxon signed-rank test for SCS-Fr subscales.

		BFI-Fr				
		E	A	C	N	O
SCS-Fr	I	.163	.019	.107	-.156	.282*
	MH	.107	.599**	.167	-.090	-.028
	R	.066	.254*	-.207	.278*	.086

Note. † = approaching significance at p < .10; * = significant at p < .05; ** = significant at p < .01. For BFI-Fr: *E* = Extraversion; *A* = Agreeableness; *C* = Conscientiousness; *N* = Neuroticism; *O* = Openness. For SCS-Fr: *I* = Independent; *MH* = Maintain Harmony; *R* = Relational.

Table 11: Bivariate correlations between the French Se f-Construal Scale (SCS-Fr) and the French Big Five Inventory (BFI-Fr) subscales.

2.3.4. Discussion

The present data appears to provide moderate support for the test-retest stability of the SCS-Fr and initial support for its criterion-related validity. Indeed, subscale scores correlated moderately across times even though no significant mean differences were found for either *I* or *R* subscales. A significant between-time difference was found for the *MH* subscale, however, as stated above, we feel this may be due to the tighter relative distribution in the scores, and thus may not be cause for concern. To the best of our knowledge, no test-retest stability results for the Singelis SCS (1994) are available in the literature for purpose of comparison. For reference, the RISC scale (Cross, Bacon, and Morris 2000b) shows good stability over a 2-month period (test–retest reliability is .73 and .63). The moderate correlations can be due to our bigger test-time interval. Also, as indicated by (Cross, Bacon, and Morris 2000b), measures of self-construals potentially entertain specific relationships with affective states such as self-confidence and self-esteem. Our moderate test-retest reliability may result from such state-like dimensions of the SCS scale. Lastly, the consistency fragility of the SCS-Fr subscales might induce extra-variability impairing the test-retest process.

The correlational analysis between SCS-Fr and BFI-Fr subscales provides the basis for criterion-related validity. Indeed, the hypothesis derived from (Cross, Bacon, and Morris 2000b) that the interdependent scales would

correlate positively with *Agreeableness* was verified. No such relationship, however, was found with *Extraversion*. Although not hypothesized *a priori*, the positive correlation between SCS-Fr *R* and BIF-Fr *N* echoes relationships found between interdependence and vulnerability to anxiety and depression. Indeed, (Yoon and Lau 2008) suggest that a highly interdependent profile may expose individuals to other-imposed pressures and expectations, thus leading to heightened concern over making mistakes. Such an interpretation would appear consistent with the content of SCS-Fr *R* items. Finally, a positive correlation was found between SCS-Fr *I* and BFI-Fr *Openness*, as posited based on the existing literature. This suggests that the stronger an individual's independent self-construal, the stronger the individual's sense of originality and creativity (Plaisant et al. 2010), which corroborates with past research on self-construal (Cross, Hardin, and Gercek-Swing 2010).

2.4. Conclusion

The overall aim of the present study was to present the steps followed in order to methodically translate the French version of Singelis' (1994) 24-item Self-Construal Scale. Whilst study 1 pertained to the inventory's internal consistency and latent structure, study 2 related to its criterion-related validity and test-retest stability.

Factor analyses – both exploratory and confirmatory – carried out in study 1 suggested that a 14-items three-factors structure may present the most appropriate fit for the SCS-Fr, namely a 5-item "*Independent*" self-construal factor (*I*), a 5-item "*Maintain Harmony*" self-construal factor (*MH*), and a 4-item "*Relational*" self-construal factor (*R*). However, future research considering a two unipolar axis conceptualization of the self-construal might opt for the 15-items two-factors structure with a 6-item "*Independent*" self-construal factor and a 9-item "*Interdependent*" self-construal factor. In both cases, internal consistencies are poor, a fact now recognized in the SCS literature (Cross, et al. 2011). The data collected in study 2 provide only moderate evidences for the validity of the newly-translated inventory. Test-retest correlations were lows, a property of the scale which might be due to the potential specific relationships between self-construal and affective states such as self-confidence and self-esteem (Cross, Bacon, and Morris 2000b). Future use of the SCS-Fr may therefore aim to further investigate these potential relationships with other scales. This study also provides a moderate initial criterion-related validity. In order to firmly test this criterion-related validity on the French population, further research including measures of pro-social tendencies and/or behaviours may be conducted (van Baaren et al. 2003).

The main limitation of our study resides in the fact that the majority of our participants are students. This limits the generalization of our results and may be a potential source for the poor internal consistency of the scales. Further studies should be conducted with more diverse populations varying in age, socio-professional background and ethnicity to capture a larger spectrum of the self-construals present in the French population.

From a methodological point of view, this study outlines a lack of guidelines in the literature regarding the threshold to be used for item deletion based on factor loadings. While (Singelis 1994) initially used a threshold of 0.35 with a Principal Component estimation method, we chose a lower threshold of 0.25 in association with a Principal Factor estimation method. This estimation method, based on the common variance within the data set, provides lower loadings on estimated factors, hence justifying the lower cut-off value. Other thresholds were however tested for exploration's purpose. Whilst a threshold of 0.20 led to the same result, a threshold of 0.30 was too restrictive to preserve the original questionnaire's factors (13 items deleted out of 24).

Authors interested in the Self-Construal construct should consider the various limitations revealed in this study. We attempted to replicate at best factor structure of the (Singelis 1994) without succeeding to provide a proper "validation" of the scale. However, one might consider the three or two dimensions if the influence of our perception

of ourselves such as preferences in design (Zhang, Feick, and Price 2006), stereotypes (Bry, Follenfant, and Meyer 2008b) or perception of the seriousness of environmental issues (Conte and Bonnefoy 2009b) is the study focus.
Regarding the use of the SCS in this PhD thesis, the two factor structure is chosen to fit the two polarities model of personality, SCS independent being assimilated to agency and SCS interdependent to communion. However, the low consistencies of the scales encourage us to take these scales with caution. One possibility to improve reliability is to have more items by scales, solution possible thanks to the presence of two other related questionnaires about Narcissism.

3. INTEGRATIVE MODEL: PATH MODEL ANALYSIS

The second part of this chapter aims at validating the hypothesized model (HIDID) we proposed based on assessment tools of individual differences validated in French. Figure 35 shows the integrative model where the various components are associated with the subscales used to measure it.

This model proposes to predict individual differences in empathic traits through their associations with emotion regulation and pro-social orientation (also called communion). Defined as three different levels of maturity in empathic functioning, personal distress, empathic concern and perspective taking are all supposed to be dependent on emotion regulation (measured via alexithymia ALEX). Personal Distress (PD) is associated with poor emotion regulation abilities, the distressed individual being overwhelmed by the emotional arousal. In opposition, empathic concern and perspective taking require good emotion regulation abilities in order to overcome self-oriented emotional arousal and engage in compassion and concern feelings. In addition, engaging in an other-oriented empathic process (EC or PT) supposed to be motivated to do so, although personal distress represent a more systematic reaction to emotional event. Thus, the pro-social motivation of communion (here measured as self-construal interdependence INT) is supposed to be positively associated with empathic concern and perspective taking.

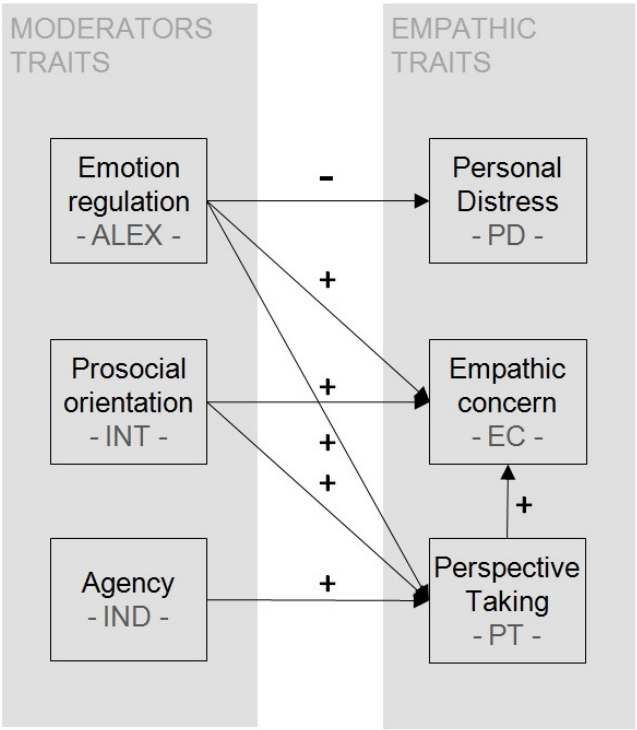

Figure 35: Proposed hypothesized model HIDID

Finally, the empathic trait of perspective taking induces a tendency to take the perspective of others, a process which foster empathic concern feeling. As a consequence, we postulate that perspective taking is positively associated with empathic concern. Perhaps the most speculative hypothesis is the positive link between agency (here measured as self-construal independenceIND) and perspective taking: the core idea is that perspective taking tendencies emerge from the experience of position exchanges in cooperative processes which develop the sense of agency out of intersubjectivity.

This study consists in administrating the selected questionnaires to a large sample population in order to be able to estimate the full model.

3.1. Data collection

A total of 231 French-speaking University students (51 female, 180 male) took part in the present study. This sample was the same sample that the first group used in the SCS validation. Participants, aged 19.34 years on average (*SD* = 1.39), took part on voluntary basis. Each participant filled in a questionnaire package comprising five self-report questionnaires, namely:

- TAS20: Cronbach's alpha for DIF, DDF, and EOT subscales in the present study were .729, .678, and .363.
- IRI: Cronbach's alpha for EC, PT, PD, and F subscales in the present study were 664, .630, .713, and .732.
- SCS: Cronbach's alpha for IND, and INT subscales in the present study were .52 and .66.
- HSNS: Cronbach's alpha for VN in the present study was .717.
- NPI: Cronbach's alpha for GN in the present study was .612.

As a general remark, all internal consistencies of the various used subscales are just acceptable. This might reveal a characteristic of our sample population: the youngness of the participants might have leaded to poor coherence across responses. As a future work, this study should be reproduced on an alternative sample population of mature adults.

3.2. Data analysis

In order to assess the integrative model, we undertook the analysis of path models from the structural equation model family. Multivariate normality with all the subscales together was respected enabling us to use Maximum likelihood estimation methods using LISREL version 9.1 for Windows. In order to evaluate our integrative model and converge toward a more appropriate model in case of misspecifications, we follow an iterative approach combining the analysis of zero order correlations and path model evaluation at each step.

One limitation of the set of tools we used has been highlighted in the previous section: the SCS lack internal consistency, particularly for the subscale IND. As our objective is to assess the articulation of agency and communion within our integrative model, the contribution of other scales taping the same constructs as IND and INT could be used to improve reliabilities. As previously mentioned, two scales measuring vulnerable and grandiose narcissism were also administered to our population. Each scale has potentially several items inversely related to the concepts of agency and communion:

- Grandiose Narcissism (measured with the NPI) includes items related to enhance leadership which is assumed to be related to agency (e.g., "*I like initiating new fashions and trends*")
- Vulnerable Narcissism (measured with the HSNS) includes items related to enhance egoism which is assumed to be inversely related to communion (e.g., "*I don't like to share my successes with others*")

Thus, a first step in our analysis was to examine if the joint use of items from narcissism and self-construal could improve reliabilities of agency and communion estimation.

3.3. Communion and Agency

A first exploratory factor analyses (EFA) was done including all items from the SCS-INT and HSNS to assess if a common factor would emerge close to the definition of communion. As in the previous study, we used a principal factor estimation method with oblique promax rotation. Investigation of the scree plot indicated a clear cut at a three

factor solution (Figure 36). Looking at the loadings, the first factor included all HSNS items excepted item 2, 4 and 5, the second factor include all SCS items excepted items 13 and 18. From this clear SCS-HSNS separation, we can conclude that no overlap emerged. As a measure of communion, we keep the SCS-INT as validated in the previous chapter, with a Cronbach of .66.

	1	2	3
HSNS8	0,622	-0,133	0,068
HSNS7	0,529	0,074	0,402
HSNS9	0,507	-0,269	0,039
HSNS6	0,503	-0,048	0,203
HSNS3	0,461	0,191	0,387
HSNS1	0,442	0,103	0,239
SCS23	-0,095	0,561	-0,254
SCS16	0,004	0,499	-0,03
SCS22	-0,021	0,485	0,062
SCS24	-0,035	0,46	-0,277
SCS21	-0,005	0,421	0,168
SCS20	-0,051	0,299	-0,056
SCS14	-0,017	0,295	0,01
SCS15	-0,056	0,24	-0,023
SCS19	0,14	0,203	0,099
SCS17	-0,046	0,138	-0,027
HSNS2	0,446	0,072	0,597
HSNS4	0,257	-0,11	0,427
HSNS5	0,371	-0,132	0,38
SCS13	0,064	-0,074	0,374
SCS18	0,006	0,15	0,162

	1	2	3
NPI13	0,82	-0,106	0,014
NPI19	0,766	-0,219	0,046
NPI20	0,673	-0,072	-0,06
NPI21	0,58	-0,243	0,051
NPI16	0,528	0,106	-0,005
NPI12	0,452	-0,136	-0,01
NPI18	0,421	-0,023	0,007
NPI8	0,399	0,048	-0,149
NPI7	0,396	0,076	0,177
NPI5	-0,32	0,269	-0,073
NPI2	0,303	0,012	0,118
SCS10	0,02	**0,649**	0,157
SCS11	0,091	**0,509**	0,191
NPI9	-0,187	**0,457**	0,236
SCS9	-0,104	**0,422**	-0,02
SCS4	0,071	**0,366**	0,254
SCS1	0,108	**0,347**	0,207
NPI10	-0,219	**0,315**	0,218
NPI11	0,077	**0,3**	0,268
NPI1	-0,044	**0,29**	0,034
SCS6	0,03	**0,286**	0,267
NPI14	-0,147	**0,258**	0,172
NPI15	0,206	0,229	0,03
SCS8	-0,142	0,216	0,11
SCS3	-0,021	0,215	-0,142
SCS5	-0,103	0,209	0,044
SCS12	-0,056	0,177	0,017
NPI4	0,032	0,255	0,584
SCS7	0,002	0,017	0,542
NPI6	0,003	0,119	0,519
NPI3	-0,024	0,207	0,271
NPI17	0,13	0,091	0,221
SCS2	-0,024	0,023	0,113

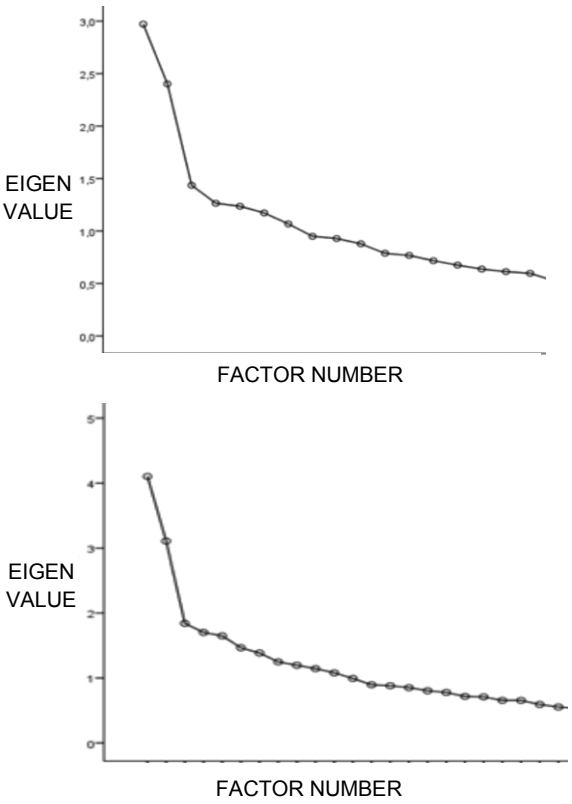

Figure 36: Two EFA performed on narcissism and self-construal items. Both fit a three factors structure

A second exploratory factor analyses (EFA) was used including all items from the SCS-IND and NPI to assess if a common factor would emerge close to the definition of agency. We used a principal factor estimation method with oblique promax rotation. Investigation of the scree plot also indicated a clear cut at a three factor solution. Looking at the loadings, the first factor included only NPI items. The second factor included most of the SCS-IND items apart from items 2 and 7, and also 6 items from the NPI. When considering items which loaded on this factor only above 0.25 (as in the validation of the SCS), 11 items remains, 6 items from the SCS-IND and 5 from the NPI. Interestingly, 5 of the 6 items selected from the SCS-IND are the same as the one validated in the SCS validation study. When considering this selection, the cronbach alpha was of 0.61 (instead of 0.52) which show an increase in reliability while keeping the construct validity of SCS-IND. In order to use this hybrid version of agency, we computed the factor scores of this second factor hereafter called IND-N.

3.4. Model evaluation

Before evaluating our model, all variables were standardized (z-score). The evaluation of the integrative model is an iterative method, from the attempt to confirm the presuppose model to the refinement of a more adequate solution.

3.4.1. Step 1: Confirmation

We first computed the zero order inter-correlations among our 6 variables (Table 12). According to our hypothesized model, we would expect 7 significant correlations within this table. 4 of these expected associations were confirmed (significant and with the good sign):

- ALEX is positively associated with PD
- INT is positively associated with EC
- INT is positively associated with PT
- PT is positively associated with EC

Thus, 3 expected correlations did not appear to be significant:

- ALEX is not negatively associated with EC
- ALEX is not negatively associated with PT
- IND-N is not positively associated with PT

Lastly, 2 unexpected correlations appeared to be significant:

- ALEX is positively associated with INT
- PD is positively associated with EC

		ALEX	INT	IND-N	PD	EC	PT
ALEX	r	1,000	0,144	0,011	0,267	0,072	-0,055
	p		0,028	0,872	0,000	0,277	0,402
INT	r		1,000	0,105	-0,005	0,417	0,206
	p			0,111	0,941	0,000	0,002
IND-N	r			1,000	-0,096	0,015	-0,078
	p				0,145	0,823	0,237
PD	r				1,000	0,181	-0,055
	p					0,006	0,405
EC	r					1,000	0,296
	p						0,000
PT	r						1,000
	p						

Table 12: Zero order inter-correlations among the 6 variables of the model

Given this only partial similarities between expected and observed correlations, the path model resulting from this schema should show relatively poor fit statistics. The resulted path model is presented in Figure 37.

The model show only partial goodness of fit (or partial badness): chi^2 (df = 5, N = 231) = 15.099, p < .01; SRMR = .0433; Root Mean Square Error of Approximation (RMSEA) = .0894 and Comparative Fit Index (CFI) = .90. Although absolute indicator SRMR and the CFI reveal good overall fit, the more restrictive chi^2 reject the hypothesis that there is no discrepancy in the model. Additionally, RMSEA indicate relatively poor parsimony of the model: the model is too complex given the pattern of covariance.

Before going into the interpretation of estimates of paths, a look at the fitted residuals matrix (Table 13) indicate that only the association between PD and EC is not correctly accounted. This seems coherent with the zero order correlations presented before: among the two significant correlations not expected in the model, the ALEX-INT association is automatically modeled as endogenous (predictors) are allow to covariate, leaving the PD-EC associations the only not modeled.

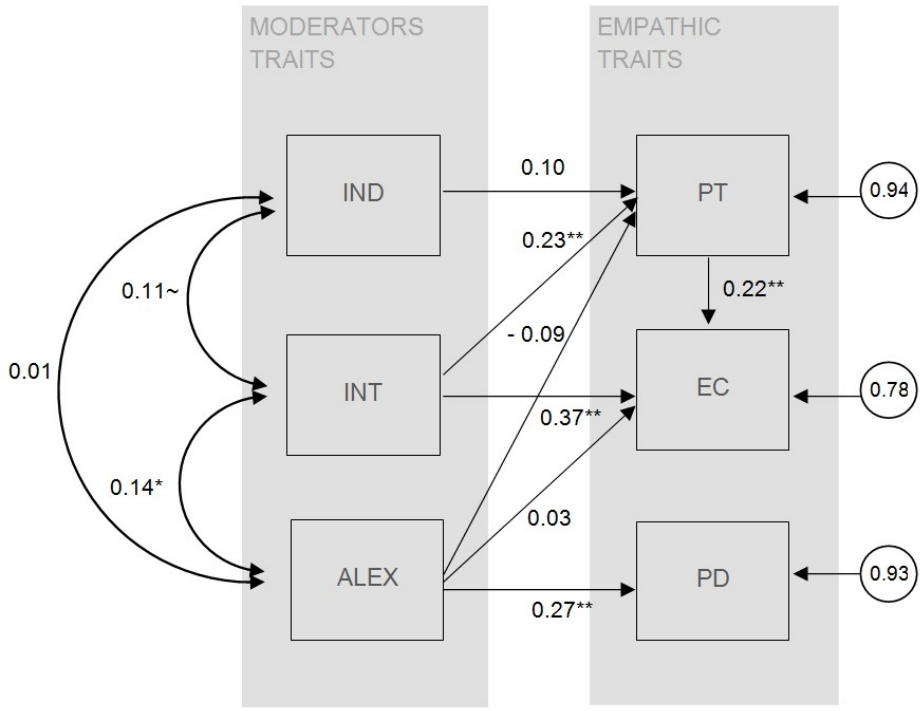

Figure 37: resulting path model of step 1

		ALEX	INT	IND-N	PD	EC	PT
ALEX	res	0,000	0.000	0.000	0.000	0.000	0.000
INT	res		0,000	0.000	-0.043	0.000	0.000
IND-N	res			0,000	-0.084	-0.006	0.000
PD	res				0,000	**0,161**	-0.040
EC	res					0,000	0.000
PT	res						0,000

Table 13: Fitted residuals from the model in step 1

Looking at estimates of the path model, 3 path appeared not significant, probably the cause of the poor parsimonious indicator (RMSEA). First, the path from ALEX to EC was not significant, and from ALEX to PT was only nearly significant ($p<0.1$). This result is in line with the zero-order correlations presented in first place. The fact that alexithymia does correlate only with PD is surprising given recent conclusions that "*various self-report measures of empathy, e.g., IRI (interpersonal reactivity index), show that alexithymic personalities report to have less empathic concern for others and reduced tendency for perspective taking in both community and psychiatric/clinical populations*" (Patil and Silani 2014). However, a closer look at the study proposed by (Grynberg et al. 2010) reveal a different pattern of associations between "*affective*" alexithymia (association of the DDF and DIF subscales) and "*cognitive*" (EOT subscale). Therefore, a refinement of the model would be to differentiate the two ALEX-A (for affective) and ALEX-C (for "*cognitive*") in the following step. We expect ALEX-A to be related to PD positively and to EC negatively (the affective part of alexithymia being associated with the affective part of empathy) and ALEX-C to be related to PT (the cognitive part of alexithymia being associated with the cognitive part of empathy). Secondly, the path from IND-N to PT is only nearly significant ($p<0.1$) and in the opposite of the expected direction. This

near absence of association was also noted in the zero-order correlations table 12. Two possible explanations can be drawn from this discrepancy: or the theory on which this path was based is wrong, or the IND-N measure does not measure what it is expected to measure. The first option is hard to discuss given the novelty of this line of research (the hypothesis that consider perspective taking as emerging from intersubjectivity and being associated with a sense of agency) and could be an interesting future work. Concerning the second possibility, a related debate is to whether self-construal independence measure autonomy or agency (Kagitcibasi 2005)(Hazel Rose Markus and Kitayama 2010). If IND-N is conceptually closer to autonomy defined as separation from others, it appears unlikely that the variable should correlate with PT, a negative correlation could even be speculated (being separate from others limit the experiences of intersubjectivity and thus the development of perspective taking). IND items such as "*My own identity, independent from others, is important for me*" seems to be closer to a separateness from others definition of autonomy, and other items such as "*I behave in the same way at home and at work*" seems to capture a sense of situational distance related to an agency feeling. Thus, both autonomy and separateness seem to appear in a face validity observation of IND's items which make it difficult to conclude about what IND really measures. The Vulnerable Narcissism construct is not at all associated with agency, but have some relation to separateness in its items taping egoistic behaviors. Interestingly, the correlation between IND-N and VN is significantly positive (r=0.146, p=0.026). This result provides an initial confirmation that the IND construct does not measure adequately agency. Investigating more valid measurement tools of agency is an important line for future researches.

For the following of this analysis, we decided to drop the IND-N scale, and to investigate the relative contributions of ALEX-A and ALEX-C to the model. The association between PD and EC will be discussed in the next step.

3.4.2. Step 2: Refinement of emotion regulation contributions

In order to investigate the different contributions of ALEX-A and ALEX-C to the model, we first run the zero order inter-correlations among these two variables and the individual differences in empathy (Table 14). The correlation patterns reveal clear discriminant validity: on one hand, ALEX-A correlates positively and exclusively with PD, and on the other side ALEX-C correlates negatively and exclusively with PT which is mostly in line with our expectations. The main limitation is the absence of correlation between ALEX-A and EC. One possibility would be that the correlation between PD and EC act as a suppressor: removing the shared variability between PD and EC from EC would reveal a negative correlation between ALEX-A and EC. This hypothesis can be verified by looking at the resulting path model or a partial correlation. The partial correlation between ALEX-A and EC while controlling for PD was not significant (r=0.041, p>0.1).

		ALEX-A	ALEX-C	PD	EC	PT
ALEX-A	r	1,000	0,030	0,277	0,089	0,101
	p		0,649	0,000	0,177	0,127
ALEX-C	r		1,000	0,044	-0,020	-0,356
	p			0,507	0,757	0,000

Table 14: Zero order inter-correlations among ALEX-A and ALEX-C and the individual differences in empathy

The resulted path model is presented in Figure 38. The model show very good goodness of fit (or partial badness): chi^2 (df = 5, N = 231) = 5.792, p = .33; SRMR = .0334; Root Mean Square Error of Approximation (RMSEA) = .0265 and Comparative Fit Index (CFI) = .99. Table 15 presents the fitted residuals which show no variable left largely unexplained.

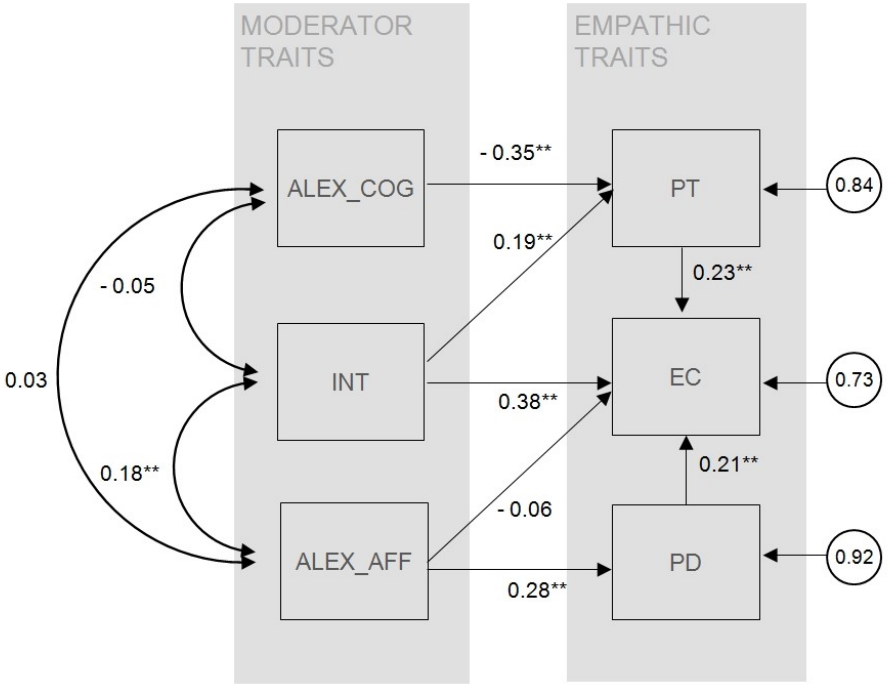

Figure 38: resulting path model of step 2

		ALEX-A	INT	ALEX-C	PD	EC	PT
ALEX-A	res	0,000	0.000	0.000	0.000	0.018	0.076
INT	res		0,000	0.000	-0.056	0.012	0.000
ALEX-C	res			0,000	0.036	0.084	0.000
PD	res				0,000	-0.036	-0.062
EC	res					0,000	-0.018
PT	res						0,000

Table 15: Fitted residuals from the model in step 2

Looking at estimates from all paths, all estimates go in the expected direction (Figure 38). However, the relation between ALEX-A and EC fails to be significant (p=0.16). Even if often in the literature authors tend to associate affective alexithymia with empathic concern, our result contradict this fact, focusing the effect of affective alexithymia on the impact of personal distress. Looking at the correlations reported in (Grynberg et al. 2010) between the subscales of the TAS20 and the IRI, EC correlates very weekly with DIF (r=-0.07, p>0.05) and DDF (r=-0.12, p<0.01). Instead, authors argue that EC is more associated with the cognitive side of both empathy and alexithymia. Following the rationale of our path analysis, we would argue that EC is associated to more cognitive phenomenon only throughout its association with PT. The effect of PT put aside, it is unclear in our study what the emotion regulation component of EC is. EC appears to be driven by INT (i.e., communion motives) as well as by PD. Related to this last association, one explanation is that both PD and EC emerge within the context of another's emotion. Thus, every emotion episode necessary involve both PD and EC, their respective importance being modulated by ALEX-A, INT and PT.

3.4.3. Step 3: Final model

The final model is the same as precedent without associations between ALEX-A and EC (Figure 39). The model show very good goodness of fit (or partial badness): chi^2 (df = 6, N = 231) = 6.139, p = .41; SRMR = .0335; Root Mean Square Error of Approximation (RMSEA) = .0202 and Comparative Fit Index (CFI) = .996.

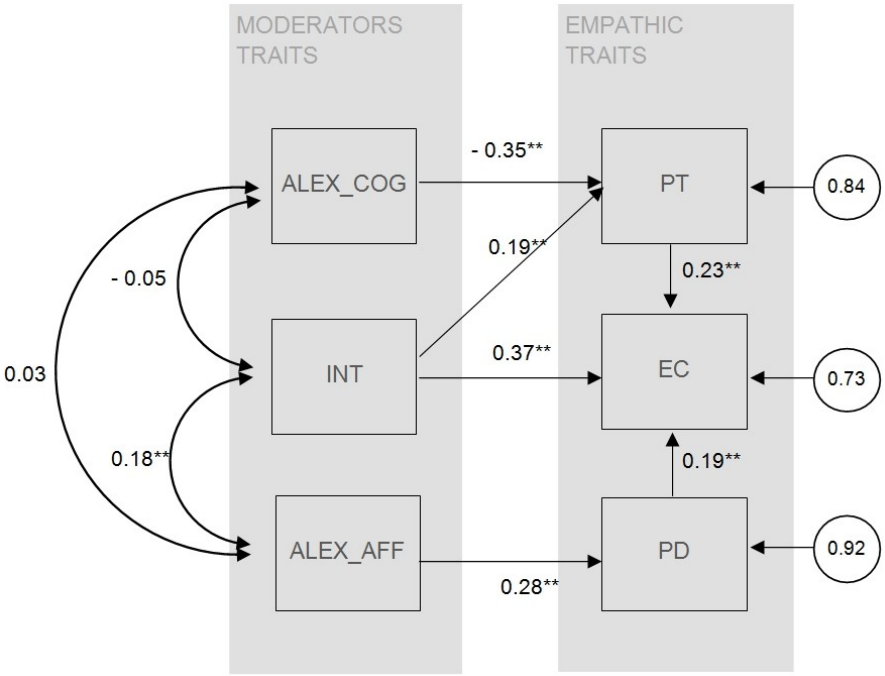

Figure 39: Final path model

3.5. Discussion

The path analysis presented in this chapter is the first to investigate together the nomological framework formed by the various components of empathy (IRI), emotion regulation (TAS20) and self-construal (SCS). We undertook this confirmatory approach based on our review of the literature. In an iterative process, we examined and rectified the proposed model to fit at best the observed data that we collected while maintaining the soundness of the theoretical background.

The first issue we met was the absence of association between the variables we considered as agency (IND-N) and perspective taking. Discussing the potential sources of this discrepancy, it is probable that a lack of validity of the scale (IND-N) would be responsible rather than a misinterpretation of the theory. This question needs further investigation with alternative agency scales to be clarified. Interestingly, we noted in the state of the art that the RFT based FID might be related to a sense of agency. Thus, the last study of this chapter will aim at investigating the associations between the FID construct and the variables of the hypothesized model, with in mind the hypothesis that RFT based FID only (compared to EFT based FID) is associated with variable related to agency: self construal independence, perspective taking and cognitive alexithymia.

The second important finding of this approach is the clear necessity to differentiate the two aspects of alexithymia: the more affective (composed of DDF and DIF) being solely associated with personal distress and the more cognitive (composed of EOT) being solely associated with perspective taking. Although not a priori accounted in the model, this proposition is coherent with most recent findings (Grynberg et al. 2010) and the idea that more mature empathic trait might be associated with more mature emotion regulation abilities. However, empathic concern was not associated with any emotion regulation variables. One possible explanation for this discrepancy is the concept of emotion regulation as measured by the TAS20: the affective component (DDF and DIF) is clearly related to an ability to process one's own emotion and the cognitive component (EOT) is more related to a greater reliance on suppression strategies rather than re-appraisal ones. In contrast, the few findings which related empathic concern to

emotion regulation emphasized the role of effortful control (Decety and Ickes 2011): "*effortful control is defined as the efficiency of executive attention – including the ability to inhibit a dominant response and/or to activate a subdominant response, to plan and to detect errors*". Although in our review we pointed the fact that alexithymia is related to effortful control (Gu et al. 2008), the two constructs might overlap only partially and a better distinction might help to differentiate the different emotion regulation processes behind each empathic traits. In our initial model, we built on the doll model of personality from (Waal 2012) considering them as different degrees of empathic maturity. In our understanding, emotion regulation was a key component at each stage, some authors arguing that emotion regulation is essential for the three facets of empathy. Our findings do not contradict this view but advocate for a more parallel account of the three facets of empathy in terms of individual differences: as empathy is a multidimensional construct, emotion regulation should be decomposed in multiple parallel processes. In (Decety and Svetlova 2012), authors describe this more parallel but additive view of empathy: "*while it is tempting to propose that empathy develops on a continuum from implicit/intuitive and nonverbal to explicit/reflective and verbalizable, several evolutionarily conserved adaptations illustrate that social brain has evolved by accretion. Rather than replacing older structures with newer ones, evolution is a patchwork of addition. These additions are integrated with older elements, but do not replace them and do not necessarily control them*".

Lastly, personal distress and empathic concern share a significant amount of variance which cannot be explained by emotion regulation or pro-social motives. We argue that this commonality comes from the inherent existence of both PD and EC in any experience of empathy, contrarily to PT.

Together, these findings bring some insights in the hierarchical organization of the individual differences we considered as essential for bodily interpersonal processes. First, it is clear that in our model, we need to make the difference between affective and cognitive emotion regulation. What we initially thought to be an association between general emotion regulation and synchronization quality can be specified by using the affective instead of general component of emotion regulation. Secondly, we previously assumed that empathic concern would cumulate the advantage of emotion regulation (greater quality of synchronization) and communion (greater quantity of synchronization). Given the result of our path analysis, it appears that empathic concern is not associated with emotion regulation as measured by alexithymia. Also, in addition to communion, empathic concern is influence by both personal distress and perspective taking which make difficult to draw hypotheses: personal distress is assumed to be related to weaker quality and perspective taking to greater quality of synchronization. Perhaps a less speculative hypothesis would be to solely hypothesize greater quantity due to its associations with communion. Finally, perspective taking does not change in terms of hypotheses, even if it association with agency has not been evidenced. Here are the reviewed hypotheses:

- Communion : greater quantity
- Agency : greater leadership
- Affective emotion regulation : greater quality
- Personal distress : weaker quality
- Empathic concern : greater quantity
- Perspective taking : greater quantity, greater quality and greater leadership

4. FIELD INDEPENDENCE / DEPENDENCE IN THE INTERPERSONAL DOMAIN

The third and last part of this chapter aims at investigating the associations between the individual differences of our model and the perceptual style of Field Independence Dependence (FID). Although during the early age of the FID construct development it has been argued that FID is strongly related to social phenomena (Herman A. Witkin and Goodenough 1977), modern investigations using the FID in social situations are scarce. However, the links between FID and some interpersonal phenomena (van Baaren et al. 2004), bodily phenomena (Isableu et al. 2003) and its possible link with the agency (Pfeiffer et al. 2013) dimension of a two polarities model of personality suggest that FID is potentially an insightful individual differences for the understanding of how individuals differentially interact with others. In the state of the art, we argued that there is an essential difference between the two ways to measure FID: the Embedded Figure Test (EFT) and the Rod and Frame Test (RFT). These measures consistently share about 20% of their variance assumed to represent the core of FID. Our argumentation against this consideration was based on two facts. First, the two measures show divergent associations when investigated together, EFT being more closely related to cognitive abilities than RFT. And secondly, both measure share the required ability of good sensory discrimination, a phenomena assumed to link to fluid intelligence but not the essence of FID. Following this rationale, the RFT appears to better capture a preferred way to interact and orient the body with the environment: FI individuals rely more on internal proprioceptive-based referents and FD individuals rely more on external visual-based referents.

Our original main hypothesis was that RFT only would be associated with agency related variable such as IND-N and ALEX-C and by consequence to PT: Field Dependent (FD) individuals being less agentic in nature. However, the results from the previous study call for caution when investigating IND-N. The agentic nature of IND-N was not confirmed and a closer association with separateness was assumed. Thus, interpretations will consider this fact with caution. We expect no correlations regarding EFT.

4.1. Data collection

The RFT and EFT are two perceptual tests more difficult to administer than paper-and-pencil questionnaires. The RFT needs to be administered one individual at a time with careful instructions in order to ensure the good understanding of the goal of the test (align the rod to the subjective vertical) without priming the individual in using any type of strategies. The EFT exists in a group version: the Group Embedded Figure Test (GEFT). The difference is that the GEFT is administered to a group of individual who should perform the test within a given time. Both were administered to individuals from the population sample of the precedent study (231 French-speaking University students, 51 females, 180 males). In total, 171 students performed the RFT and 126 students performed the EFT. These two groups overlap only partially, resulting in a group of 84 individuals who performed both. RFT frame effects are calculated using the (Nyborg 1974) method. In our analysis, the scores of the EFT are reversed to make both EFT and RFT oriented in the same way: more FD individuals score higher and FI individuals score lower.

4.2. Data analysis

In order to assess the associations between perceptual styles and individual differences from our model, we conducted correlation analyses. As a second step, we explored the usefulness of various indicators computed from temporal strategies of individual while performing the RFT. Regarding the RFT scores, an outlier analysis was performed based on the inter-trial variability: an individual having a large inter-trial variability result in an unreliable overall

RFT score. 24 individuals were removed, 147 RFT scores remaining for the study (and 71 individuals who performed both).

One theory proposed by (Konrath, Bushman, and Grove 2009) is that FID is not merely associated with autonomy or communion but rather by the combination of high self-focus and low other focus, a prototype which they named "*atomized self*" (Figure 40). In the 2D space formed by agency and communion, it is equivalent to considering only one diagonal of the space. To do so, authors computed a difference variable from autonomy scores minus communion scores. In order to investigate this hypothesis, we computed this difference variable (IND-N – INT) as well as the other diagonal equivalent to an addition (IND-N + INT). While the first variable capture a more unipolar orientation (either self focus or other focus), the second variable capture a more adaptive combination of agency and communion: individuals scoring high on both agency and communion score higher on this variable.

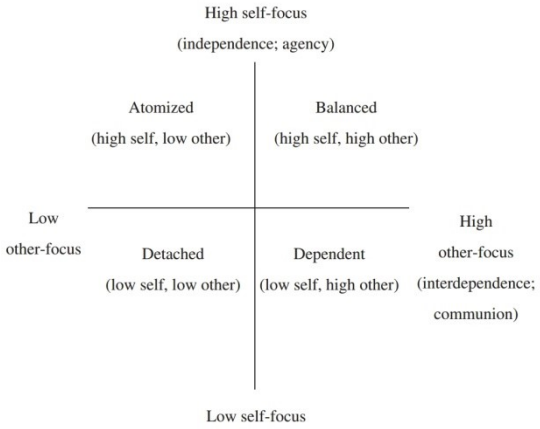

Figure 40: Four types of self from (Konrath, Bushman, and Grove 2009)

4.3. Results

4.3.1. FID in our model

We first computed the correlation between RFT and EFT: better performances on the EFT were associated with better performances on the RFT ($r=0.458$, $p<0.001$), the size and the sign of the correlation being coherent with the past literature.

Secondly, we computed the correlations between each of the FID measures and the various individual differences from our model. RFT correlations were computed from the full sample (n=147) as for EFT correlations (n=126). Figure 41 shows the various correlations which are all very low.

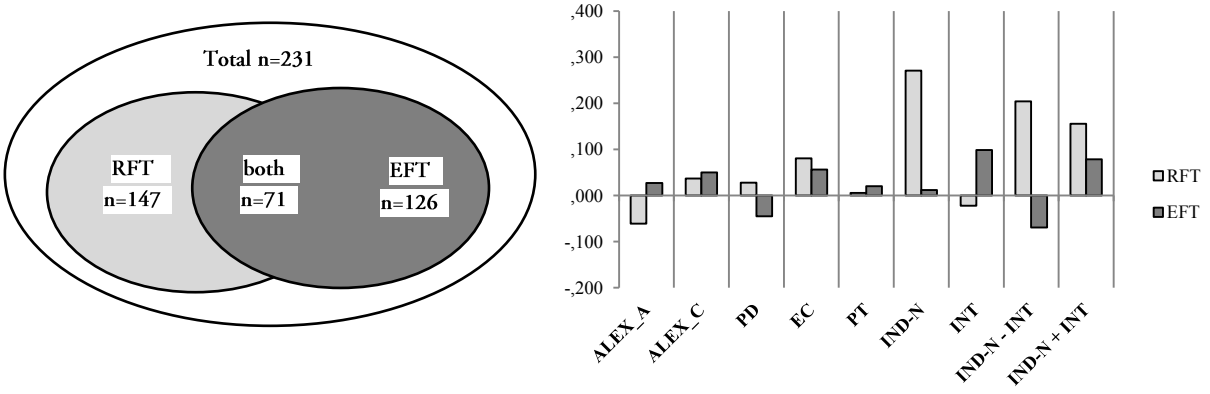

Figure 41: a) Representation of the population samples b) zero order correlations between FID measures and individual differences from our model

Only two correlations appeared to be significant: the correlation between RFT and IND-N and between RFT and IND-N – INT. Although we initially expected a negative correlation between RFT and IND-N (FD individuals being less agentic), our results evidence the opposite: FD individuals appear to be more agentic. Considering the

limitation highlighted in the previous study of IND-N, another interpretation would be that FD individual are more separate from other in nature. Both interpretations are counter-intuitive and against the general hypotheses in the literature that FD are more socially oriented than FI people. Given the combined limitations of the RFT measure and the IND-N scale, it appears preferable to consider this result as intriguing and calling for further explorations (e.g., use various reliable measures of autonomy and agency). In addition, we found no association between FID measures and PT which limit the interpretation of PT as emerging from an enhance sense of agency.

The absence of correlations between FID measures and all the other individual differences confirmed the fact that FID cannot be associated with general sociality as it is often done in the literature. Additionally, the EFT measure was not associated with IND-N which is inconsistent with the result from (Konrath, Bushman, and Grove 2009). However, in their study the EFT correlation with autonomy related variables were weak although significant. Again the current lack of precise specification of the concepts autonomy and agency does not help to further draw detailed interpretations. Together, the absence of correlation of the EFT in our study and the weak correlation of the EFT in (Konrath, Bushman, and Grove 2009) with autonomy call for better conceptualization of these construct (FID and autonomy) and their possible articulation. In our view, the EFT should be better considered in terms of fluid intelligence rather than FID or analytic cognitive style, a hypothesis which could be tested in future research. Another distinction which could be empathized is the difference between social agency and the sense of agency emerging from sensori-motor mechanisms. In the former, agency is associated with the sense of the self emerging from the experience of intersubjectivity and social exchange (Gillespie and Richardson 2011) and in the later agency is related to a general sense of self emerging from the multisensory integration anchored in the vestibular system (Ferre, Lopez, and Haggard 2014). As the RFT based FID seems primarily linked with the later, a better discrimination and articulation of these concepts could explain the discrepancy observed in our data.

In the state of the art, we highlighted how various variables could bias the RFT scores. One of them is individual differences in impulsivity: impulsive people act too fast making bigger errors and reflective people act very slowly making smaller errors. Thus, an impulsive individual could be considered as field dependent whereas its error is mainly due to the rapidity of the decision. To control for this, computed the difference between the RFT score (error in judging the vertical) and the performance time. We excluded 42 individuals supposed to be reflective and impulsive people, 105 individuals remaining in our sample. We performed the same correlational approach on this sample: the exact same pattern emerged, without further insights.

Finally, we tested whether the EFT, the RFT based on the large sample (n=147) or the reduced sample (n=105) could contribute to our previous final path model. We located the FID measure as a predictor linked to PT. None of the three models revealed a significant association between FID measures and perspective taking.

Together, these results do not provide any firm evidence of an association between FID and individual differences identified in the state of the art as related to interpersonal bodily processes. While this absence of relations was expected for the EFT, we expected to highlight some associations for the RFT. The discovered significant correlation is counter-intuitive and with a suspicious variable given the lack of confidence about its content validity.

4.3.2. Qualifying the RFT

Given the large possibilities for strategies and different pattern in the way individuals respond to the RFT, we decided to compute several variables from the temporal dynamic of the RFT to investigate in an exploratory fashion their associations with our individual differences. The fact that the display of rod was computerized and that individual move the rod by taping on a keyboard enabled us to log the online movement of the rod. Therefore, in addition to the final position of the rod, we have access to the time-series evolution of the position of the rod.

From this time-series, we decided to extract different variables potentially revealing various aspects of the RFT responses:

- Time (TIME): the total time to perform the test. This variable can be linked to impulsive behaviors
- Distance (DIST): the total distance covered by the rod before stopping to the final position. This variable can differentiate between individuals who explore more or less possible orientations
- Uncertainty zone (UNCER): in their strategy to find the best orientation of the rod which suit their feeling of subjective vertical, individuals first make a long movement from the starting position of the rod (18 or -18°) to a gross approximation of the vertical, and then navigate more precisely in an "*uncertainty zone*" to adjust their decision. The variable UNCER correspond to the maximum amplitude to this zone.
- Ration between active and inactive phases (RATION_AC): during a trial, individuals have phases were they move and other were they do not. Some individuals have longer inactive phases. To distinguish them, we compute a ration of the time active by the time inactive.

Correlations between these variables and individual differences of our model are presented in table 16. Apart from the previously evidenced correlation between the RFT frame effect and IND-N, no other correlations appeared significant. As we have no hypotheses about how the RFT related variables and the other individual differences might be related in a multivariate way (via linear combinations of them), we run a canonical correlation with RFT related variables as predictors and individual differences as dependent variables. The overall model did not appear to be significant preventing from going in a more detail analyses of the potential associations. Together, these results provide additional clues that the RFT is far from being directly related to such general individual differences.

		ALEX_A	ALEX_C	PD	EC	PT	IND-N	INT	IND-N -	IND-N +
FRAME	r	-,061	,037	,028	,081	,006	0,271	-,022	0,204	,155
	p	,463	,657	,738	,332	,943	,001	,791	,013	,060
DIST	r	-,061	,058	-,083	-,089	,087	,026	-,115	,108	-,067
	p	,466	,484	,315	,285	,292	,756	,165	,191	,420
TIME	r	,122	-,049	-,012	-,036	,106	-,077	-,006	-,048	-,053
	p	,140	,556	,889	,664	,201	,356	,946	,562	,527
UNCER	r	-,063	,052	-,087	,008	,121	,071	-,068	,102	-,004
	p	,451	,528	,295	,925	,145	,394	,413	,218	,957
RATIO_AC	r	-,156	,152	-,015	-,022	-,130	,123	-,013	,094	,068
	p	,058	,067	,856	,790	,117	,139	,878	,256	,412

Table 16: zero order correlations between RFT related variables and individual differences from our model

4.4. Conclusion

As identified in the state of the art, the concepts of perceptual style and field independence / dependence have great potentials in the study of individual differences in the way people bodily interact with others. However, the domain of FID suffers from conceptual debates as the validity of the use of both the EFT and RFT as reliable measures of FID. Interested in the explanatory power of FID and taking seriously the theoretical debates of the domain, we undertook the study of their association with more classical paper-and-pencil questionnaires of individual differences related to social phenomena (empathy, emotion regulation and pro-social orientation). Throughout the various analyses we performed, only one weak correlation appeared significant with a counter-intuitive sign toward the suspicious variable of self-construal independence. Regarding this correlation, we prefer to not draw tentative interpretations and call for additional studies taking more reliable measures of autonomy and agency. The fact that the EFT, the RFT and even various alternative variables from the RFT does not correlates with our individual differences reinforce our doubts about a general interpretation of FID as related to the interpersonal domain. Facing

this absence of results, we suggest two possible lines of research which could help unveil how perceptual styles impact the social sphere:

- FID assessment tools: the two classical measures of FID (RFT and EFT) are ability test in their form with various confounding variables. For example, in our study we tried to control for impulsive and reflective individuals by removing too fast or too slow people. In the state of the art we discussed several others such as style mobility or general spatial abilities. A challenging but promising route is to investigate the design of more reliable tools to distinguish mobile versus fixed and internal reference preferences (currently FI) versus external reference preference (currently FD).
- Social interaction tasks: one possible error in our consideration of FID is the inherent absence of context in the individual differences investigated. One conclusion of (Herman A. Witkin and Goodenough 1977) was that FD individual rely more on social information in uncertain context where another individual could be assumed to be a relevant source of information. Perhaps the influences of individuals' FID in the way they interact with others emerge in only specific or demanding situations requiring less habitual modes of functioning. This interpretation would be in line with researches on FID in postural control where no differences appear in the standard standing posture, whereas FI and FD people clearly adapt differently to more constraining conditions.

5. CONCLUSIONS

In this chapter, we attempted to provide empirical evidences for the validity of the individual differences part of the hypothesized model (HIDID) defined in the state of the art. To do so, we identified individual assessment tools which could potentially correspond to each of the components of our model. The IRI was used to assess the three empathic traits (personal distress, empathic concern and perspective taking), emotion regulation was assessed through the concept of alexithymia with the TAS20 and pro-social orientation and agency were associated with the concept of self-construal measured by the SCS.

While both the IRI and the TAS20 are questionnaires validated in French, the SCS remained to be examined in a large French sample population. Thus, our first study pertains to the validation of the SCS in collaboration with three researchers from two other laboratories. Although we conducted a careful step by step procedure on a very large sample of responses (n = 567), the results are mixed with the French version of the SCS showing poor internal consistencies and test-retest reliability. The psychometric weakness of the SCS has already been acknowledged in the literature (Levine et al. 2003) and our validation attempt adds to this skeptical literature about the independence/interdependence concept from (Hazel R. Markus and Kitayama 1991). However, given the large number of studies highlighting its predictive power in social cognition even with weak reliabilities, it is not surprising that many researchers continue to use it. The design of a scale related to the SCS but with more detailed conceptualization about the concept of autonomy, independence, agency, relatedness and separation would be a very fertile research project. Regarding this PhD thesis, we took this reliability issues seriously and tried to improve it via a merging with narcissism related items given their conceptual similarities.

The path analysis of our individual differences model was very insightful for several reasons. It confirmed the weakness of the self-construal independent scale which showed no clear association with related variables. In addition, the partial confirmation of our supposed model enabled us to build on our previous review of the state of the art to move toward a more adequate model without totally changing our model. More specifically, two related major changes appeared in our conceptualization of the organization of these different individual differences. First, we acknowledged the importance to consider emotion regulation as a multidimensional construct which differentially contribute to empathic traits. The more cognitive aspects of emotion regulation are more related to cognitive aspects

of empathy. However, and this is the second point, the empathic trait empathic concern in our model was not related with any emotion regulation variables. Together with the fact that the cognitive emotion regulation was not related to affective emotion regulation, these results made us reconsider the way the empathic traits are associated. Rather than three levels of empathic maturity which could be associated according to a continuous evolution of general emotion regulation ability, we re-considered the parallel aspect of these empathic traits related to three types of empathic responses and potentially parallel emotion regulation processes. Given the high goodness of fit of the path model associated with the soundness of the associated theory, we were able to refine our hypotheses about the associations between individual differences and bodily interpersonal processes.

The final part of this chapter aimed at exploring the concept of FID as a promising variable to link individual differences to bodily interpersonal processes. Our correlational evaluation revealed no associations apart from a weak association with the self-construal independence. As already discussed, the weakness and counter intuitive sign of the correlation and the limited construct validity of this scale prevent us from drawing interpretations. Our main conclusion from this study is about the absence of results: FID measures need to be refined in order to be less methodological biased and more theoretically clear. Also, the second conclusion is that perhaps the attempt to link FID measures to general behavioral tendencies is vain given the contextual nature of the concept: FID measure the way an individual interacts with its environment in some uncertainty situations. Investigating the "*general*" level or looking at a task without specific functioning modes would probably not reveal the differential functioning of FI and FD. In not enough demanding tasks, all processes are equiefficient (vicarious) leading to few interindividual differences to appear. High demanding tasks require using the more efficient processes leading hence interindividual differences to vanish and more general behavior to appear. Middle task difficulties (not too easy, not too hard) can reveal these idiosyncrasies (preferred processes used by some subjects begin to be limited). Finally, the gap between self-report measures and perceptual tests is a classical issue in psychological research: individuals often behave differently from what they think they do.

The main limitation of these three studies is the population from which they are based. With in average 20 years old, this young student population does not represent an emotionally mature audience. The clear association between emotion regulation and empathy should also be investigated in older population to free the analyses from psychological development issues. For example, (Skowron and Friedlander 1998) provide as an instruction to not administer the differentiation questionnaire to individuals under the age of 24.

In the two next chapters of this thesis, two case studies are investigated to analyze interpersonal bodily processes and individual differences. These two cases studies are based on two different collected corpora within which different individual differences were assessed. Although the rationale of this manuscript appears sequential, the collect of these two corpora appeared early in this PhD, in parallel to the analyses performed in this chapter. As a consequence, the individual differences presented in the two next chapters are not exactly similar: although alexithymia is measured in both, empathy is measured only in the second case (virtual coach) and the self construal was not assessed at all. Instead, the Five Factor model of personality was administered in both cases studies. As highlighted in the state of the art, two traits of these five can be used in relation to the model proposed in this chapter: agreeableness is close to empathic concern and mainly driven by pro-social motive and extraversion is associated with dominance behaviors and agentic behaviors. Finally, neuroticism will also be considered given its associations with self-esteem and affective situations.

CHAPTER 4

Case study 1:
job interview

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Job interviews are social interaction tasks which raises increasing interest in the HCI community. Being a key step in everyone's life, it engages our whole body and strongly arouses us. The design of an application replicating virtually this highly emotional situation would be an interesting tool to help individuals to better manage their emotions and being less affected by this potentially traumatic moment. In this chapter, we present our analysis of the role of the body of both the participants and the interviewers within this applicative context. After reviewing recent research works specifically related to this case study, we present our approach, method and collected corpora. In order to limit the range of interpersonal phenomena to be analyzed, we focus on the presentation phase of the job interview: during 5 minutes, the participant presents him/herself to the judges and the reasons of his/her application. Focusing on this phase of the interview enables us to not consider dialog related phenomena, and to focus on one type of asymmetrical interaction: the participant talks (standing) and the judges listen (seated). This task configuration explains why we give some attention to postural control and listening behaviors literatures at the beginning of this chapter. In the following, the terms interviewers, judges and assessors will be used interchangeably.

The analysis of the bodily interaction is done in two steps. First the presenting participant bodily behaviors are analyzed individually in order to provide some information about how nonverbal behaviors are associated with emotion, individual differences and perceived performance in this context. In addition to better understand how individuals nonverbally react to such situation stressor, this analysis proposes a first attempt to predict perceived performance from bodily behaviors, a key element to provide feedbacks in a job interview application. The second analysis focuses on the mutual nonverbal adjustments between the participants and the two judges. Following our conclusions from the literature review on bodily interpersonal processes, we investigate the multimodal synchrony occurring within the presentation phase of the interview. As for the first analysis the aim is twofold: provides a better understanding about the role of interacting bodies in such a constrained setup and lay the ground for the modeling of a data-driven interactive judge. Particular attention will be paid in how individual differences are related to the interpersonal bodily adjustment. The last part presents a first attempt toward such virtual listening judge.

1. JOB INTERVIEW: RELATED LITERATURE

1.1. Public speaking and interviews

1.1.1. Stress in public speaking situations

Speaking about ourselves in front of somebody is always engaging. Judgments of others are perceived as threats and the risk of failing (e.g. in a job interview) induce anxiety and stress related states (i.e. negative affects) (Harmon-Jones and Winkielman 2007). As the management of stress in companies is a main societal challenge (The World Health Report, 2001), public speaking provides a relevant scenario to analyze and train individuals in their regulation of emotions.

Lazarus defines psychological stress as the result of the comparison between the power of the environment demands (stressor or load) and the psychological resources of the person to manage these demands (Lazarus 1991), (Lazarus 2006). Stress is therefore mediated by an appraisal process with individual differences. Three types of psychological stress are identified: harm/loss, threat and challenge which all result from different situation appraisals. Psychological stress and emotions are interdependent yet not often studied together. Multiple emotions can arise from stressful situations such as anxiety, fright, guilt, shame, frustration and sadness (Lazarus 2006). Defined as such, stressful situations encompass a wide variety of situations eliciting a panel of negative emotions but also possibly some positive affects related to the challenging situation.

Several studies use a public speaking task to elicit stress. The Trier Social Stress Test (TSST) was introduced in 1993 by (Kirschbaum, Pirke, and Hellhammer 1993) for the induction of moderate psychological stress in a laboratory setting for psychological studies. The TSST test consists of a simulation of a job interview: the participant prepares during ten minutes a free five minutes presentation speech and then delivers it in front of a jury of experts. This protocol has been shown to induce stress impacting physiology, behaviors and cognition but with large individual differences (Harmon-Jones and Winkielman 2007).

Psychological studies have shown that stress impacts expressions in speech (Streeter et al. 1983), posture (Roelofs, Hagenaars, and Stins 2010), facial expressions (Wallbott and Scherer 1991), physiology (Kirschbaum, Pirke, and Hellhammer 1993) and self-report (Baggett, Saab, and Carver 1996). Studies have also shown that there were individual differences in terms of how people appraise, regulate, and express their emotions during a stressful task (collection of data limited to speech) (Schneider et al. 2012). Yet, databases of non-acted multimodal expressions of emotions (including of the full body) collected during stressful situations are not available.

1.1.2. Virtual interviewers

Simulating a virtual audience for a public speaking scenario is a recent research topic. A virtual audience can be used to help musicians to practice, combat social phobia in exposure therapy or more generally to study the effect of stress in demanding situations (Kang et al. 2014).

Virtual environment populated by a human like audience to provoke anxiety and treat social phobia is the most studied research case (Vanni et al. 2013). Often having poor fidelity appearances, animated virtual audiences have shown to be effective on the long term, behavioral animations being a key determinant of the success of the therapy. The main advantage of these virtual audiences over real world workshops is the possibility to provoke fear and anxiety in a controlled manner. By modifying the audience behaviors and attitudes, the researcher can generate a gradual exposure (Kang et al. 2014). Several researches have investigated the impact of neutral, negative or positive feedbacks from the audience (Pertaub, Slater, and Barker 2002), (Batrinca et al. 2013), with even bored or critical attitudes (Kang et al. 2014). Common to all these works is the independence of virtual audience behaviors on the participants' behaviors: audience behaviors are controlled by an experimenter (Wizard-Of-oZ) or pre-scripted but are not computed in real-time as a function of user's performance or nonverbal behaviors.

Recent research project go further by developing interactive virtual audience in scenario such as job interviews. People in unemployed situation can lack of self-confidence and need to be engaged in such situations to avoid marginalization (Anderson et al. 2013). It is important to be confronted to the challenging task of interacting with a recruiter while managing the inherent negative emotions emerging from the stressful context: our emotional reactions are used by others to infer our mood and personality (Hareli and Hess 2009). MACH is a conversational coach which gives to participants a graphical and textual feedback on the overall job interview performance based on face and voice cues (Hoque et al. 2013). The interaction is a sequential dialog with some mimicry and random behaviors displayed by the virtual agent. The evaluation of the system showed users which received feedbacks about their interaction improved their performance. The TARDIS European project proposes an interactive serious game platform where the participant interacts with a virtual interviewer: the system infers user's emotions and states of mind based on various nonverbal cues (face, voice, gestures and postures), and then generates nonverbal behaviors through an affective module following a sequential dialog scenario (Anderson et al. 2013), (Baur et al. 2013). Some aspects of the project concentrate on the reasoning process (Theory of Mind) (Jones et al. 2014), while others explore different styles of virtual interviewers: an understanding character to augment self-efficacy, create a warm and friendly climate, vs. a demanding recruiter to prepare the users for more difficult situations and train their coping abilities (Gebhard et al. 2014). Another scenario

of interview is investigated in (DeVault et al. 2014): the goal is to make the interlocutor feel comfortable to elicit self-disclosure in order to detect depressions or anxiety disorders.

Overall, these projects tend to be as much multimodal as possible, integrating voice, face, gestures to infer emotions and intentions. They also include complex dialog models to reproduce the entire interview scenario. Dynamic postural control is never considered, and the subtle interactive dynamics of the nonverbal interaction is rarely investigated: some predefined rules are provided according to the style of the interviewer.

1.2. Listeners and backchannels

1.2.1. Listeners in human sciences

In the study of conversation and until recently, Human sciences have almost exclusively focused on the speaker and the turn taking process ongoing in dialog. Dialog is considered as alternating monologues, with a "*floor*" which can be held by only one person at a time: "*the listener remains mute and invisible*", considered as a "*speaker in waiting*" (Janet B. Bavelas, Coates, and Johnson 2000). Recent approaches emphasize the collaborative nature of conversation (Goodwin 1981), where listeners are considered as co-narrators by the feedback they continuously provide during the dialog. Listeners in face to face interactions are "*addressees*" as the speaker directly addresses them. Addressees have subtle yet essential behaviors conveyed via "extra linguistics signals". In face to face, this collaborative process enables the "*grounding*": process which ensures the good mutual understanding (Janet Beavin Bavelas and Gerwing 2011).
Looking at asymmetrical dialog (where one person tells a story and the other person is merely listening), (Janet B. Bavelas, Coates, and Johnson 2000) identified two types of responses: generic responses (also called "*continuers*") which do not convey any narrative content and function as an indicator of the listener's cognitive process to help the speaker track comprehension. And specific responses (also called "*assessors*") tightly connected to the narratives which are not generically appropriate. The specific responses permit the listener to become the co-narrator of the story (Tolins and Fox Tree 2014).

Individual differences in listening styles (i.e. regardless of the situation) have also been investigated (Villaume and Bodie 2007). (K. W. Watson, Barker, and Weaver 1995) developed a listening style profile test with four different listening orientations: people, content, action or time orientations. Rather than being independent categories, individuals often combine two preferred orientations. (Villaume and Bodie 2007) proposed to form three groups which showed associations with personality dimensions.

1.2.2. Virtual listeners

Virtual humans as attentive listeners are an active domain of research. Backchannel are modeled following data driven approach (machine learning) (Morency, Kok, and Gratch 2010) or theory driven approach (rule bases model) (Poppe, Truong, and Heylen 2013). In machine learning approach, two of the most popular methods are Hidden Markov Model (HMM) and Conditional Random Field (CRF) (L. Huang, Morency, and Gratch 2011) sequential probabilistic model providing real time probabilities of apparition of discrete nonverbal signals. Models are trained on annotated datasets using various nonverbal signals (voice, head movements, facial expressions) (Morency, Kok, and Gratch 2010). With the development and efficacy of data driven approaches, the tendency is to propose multimodal models (Morency, Kok, and Gratch 2010) with an effort toward the collection of more behaviors (de Kok et al. 2010).

Some works on virtual listeners focus on the reactive aspect of backchannel and propose models of generic responses (L. Huang, Morency, and Gratch 2011). In these cases no understanding of the narrative is necessary. Another approach looks at higher processes such as state of mind and affects to guide the backchannel behaviors. In these cases

specific responses tied to the narrative structure are considered. (Wang, Lee, and Marsella 2011) propose to give varied goal and roles, to go "*deeper*" than only generic feedback. (Buschmeier and Kopp 2014) try to determine the timing of feedbacks by considering "*information need*" of the speaker which necessitates keeping track of the narrative. In the SEMAINE project (Schroder et al. 2012), recognition module of emotional state and user's words are added to guide the generation of specific responses.

When the development and evaluation of interactive listener behaviors is based on a corpus of recorded human-human interaction, the model is considered good when it can reproduce behaviors in the corpus. One issue with this ground truth definition is that backchannels are optional, which leaves a place for variations and expressions of individual differences (Poppe, Truong, and Heylen 2013). To overcome this ground truth difficulty, the common approach is to collect several listener behaviors for one speaker in order to have different backchannel strategies such as with the parallel listener consensus approach proposed in (de Kok et al. 2010). Thanks to a mediated face-to-face interaction, a corpus with three listeners for one speaker was recorded. These multiple backchannel responses are then combined into a consensus response used to train the model. The collection of corpus with multiple listeners can be done via Parasocial Consensus Sampling, a method which allows multiple individual to experience the same situation (L. Huang, Morency, and Gratch 2010).

Some recent works try to directly model individual differences in listening style rather than trying to capture a consensus. (Reidsma et al. 2011) make the distinction between cooperative and competitive (interruptive, try to take the floor) response strategies. Works on rapport agent consider only the cooperative listening behaviors (L. Huang, Morency, and Gratch 2011) (Wang, Lee, and Marsella 2011). In the SEMAINE project, an interview scenario was defined where the interviewer could have four different personalities (McKeown et al. 2012), expressed through appearance, turn taking and backchannel strategies (Schroder et al. 2012). More specifically, Extraversion and Neuroticism traits from the Five Factors model of personality (Costa and McCrae 1992) were used to generate different intuitive interactive rules (e.g. low neurotic individual mimic more). Results from perceptual analysis (Sevin, Hyniewska, and Pelachaud 2010) (Bevacqua et al. 2012) did not provide clear validation of these differentiated strategies. A contrasting result in the same project comes from (McRorie et al. 2012) where personality of the agent were correctly recognized by participants. This discrepancy in result might be due to the evaluation protocol: in (Bevacqua et al. 2012) the physical appearance is controlled and only behaviors variations are under study. In (McRorie et al. 2012), personalities were primarily recognized through stereotyped physical appearance and behaviors only "*reinforce*" the described personality. (L. Huang and Gratch 2013) studied personality of the listener and the speaker according to this same personality model: results were not coherent with formulated hypothesis (i.e. Headshakes which express negative emotions toward the speaker were positively associated to agreeableness and extraversion). Alternatively, (de Kok, Heylen, and Morency 2013) model each listener independently and without prior assumptions about their individual differences. They constituted empirically clusters of coherent listeners. In their corpus, the model with four types of backchannel strategies performed the best, confirming the functional importance of individual differences.

As machine learning model output probabilities of backchannel apparitions in real time, a threshold is often empirically defined to generate a backchannel or not. An interesting approach to induce variability in backchannel models is the dynamical threshold method proposed in (Kok and Heylen 2013) which propose to modulate online the threshold as a function of time between responses. Varying the different parameters of the dynamic function enables to model individual differences and adapt to various behaviors.

1.3. Postural control

"*Although standing upright seems straightforward and effortless to most of us, it is actually quite challenging to explain how we are able to accomplish this task*" (Shockley, Santana, and Fowler 2003).

Public speaking tasks have been studied in a multimodal manner including physiology, voice, face and gestures. Whether it is in the analysis of real human data or the modeling of virtual interviewers, whole body movements and postural control has not driven much attention.

1.3.1. Postural control as a dynamical process

Gestures or specific isolated movements with a clear onset and offset are perhaps the main way of describing bodily expressions (Kendon 1994). Often considered in the context of a conversation, gestures as co-verbal elements are concentrated on the upper body (McNeill 2008). Posture in conversational research is traditionally considered as a static body configuration. In his Posture Scoring System, Bull defines a posture as "any movement which is taken up and maintained for at least 1 second" (Bull 1987). In the Body Action and Posture Coding System (BAP), "*A posture unit represents the general alignment of one or a set of articulators (head, trunk, arms) to a particular resting configuration*" (Dael, Mortillaro, and Scherer 2012).

In both of these coding schemes, gestures are defined as movements occurring on top of static full body configurations. These static body configurations can convey specific emotions (Coulson 2004), action tendencies (Tan et al. 2010) or even the intensities of certain emotions (Kleinsmith, Bianchi-Berthouze, and Steed 2011). Unlike the traditional static view of posture, postural control is dynamical. In motor control studies, posture is defined as, "*the body automatic stabilization in the gravity force field in a standard position specific to the species*"(Winter 2009). Postural control, often synonymous of balance, is therefore the dynamical process by which equilibrium is obtained by maintaining the vertical projection of the body's center of gravity within the base of support (area under the feet) (Figure 42). Our body is always swaying around its equilibrium point and this sway can be impacted by different variables such as aging or attention (Duarte and Freitas 2010). Several theories exist to explain the functional role of this sway: sway might be a consequence of noisy processes within the human neuromotor system, a reflection of an active search process (Riccio, Martin, and Stoffregen 1992) or an output of a control process with multisensory integration mechanisms (Jeka, Oie, and Kiemel 2000) of stabilization-orientation of the whole body as an unstable structure (Latash et al. 2003).

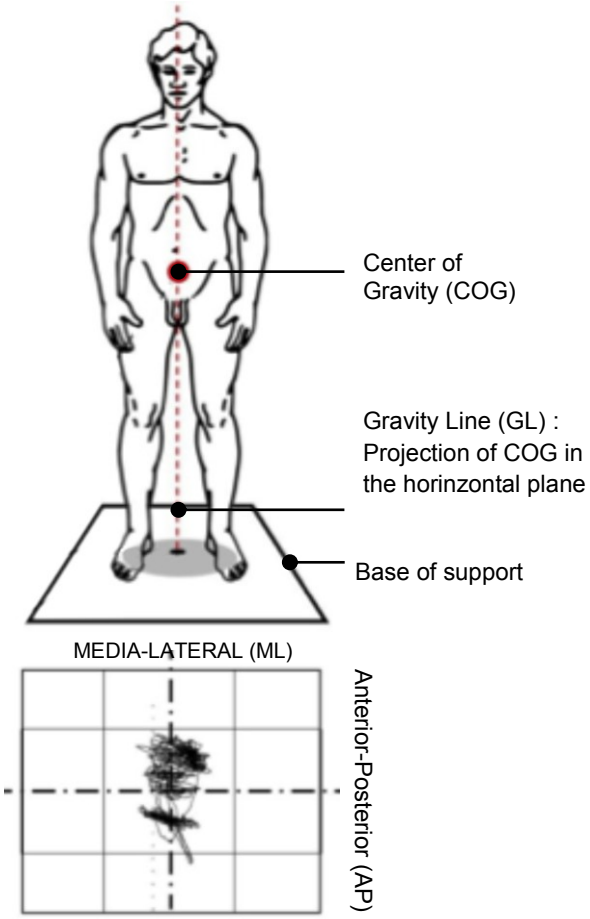

Figure 42: Representations of the COG, the GL, the base of support and displacements of the COP.

Two mechanisms are known to stabilize the posture: the modulation of muscle stiffness and the active intervention of the central nervous system (Morasso and Sanguineti 2002).

The most common way to quantify the human body sway is by the extraction of the center of pressure (hereafter called COP) trajectory through a force platform that measures the ground reaction forces. The COP is therefore "*the position of the resultant vertical component of the ground reaction force applied to the body at the ground surface*" (Duarte 2010 revision). While most of the studies analyze the COP directly, other authors advocate for a systematic decomposition of the signal. These decompositions aim at disentangling the "*complex mix of the gravity line migration and inertial forces*" (Zatsiorsky and Duarte 1999).

One approach is to consider both the COP and the of gravity (hereafter called COG) (Benda, Riley, and Krebs 1994). The center of gravity is the point of resultant of gravity forces. It is independent of speed and acceleration and is identical to the center of mass in most situations. Its vertical projection in the horizontal plane is called the Gravity Line (GL). Therefore, the difference between the CoP and the COG is the oscillation around the gravity line and represents the neuromuscular response to maintain balance (O. Caron et al. 2000). Some authors refer to it as "*a fair expression of the ankle joint stiffness and is linked to the level of neuromuscularactivity of the lower limb muscles required for controlling posture*" (Vuillerme and Nafati 2007) and have been used as a measure of rigidity (Rougier and Caron 2000). Center of gravity can be extracted via kinematic methods by combining segment positions and inertial parameters (Duarte 2010 Revision). A single marker method exists also for easy monitoring. Stabilographic methods enable to determine the gravity line from force plate data (center of pressure). The simplest method considers the body as an inverted pendulum and is equivalent to a low pass filter with the cut-off frequency determined by anthropometric data (Caron 1997). Another similar approach has been proposed in (Zatsiorsky and Duarte 1999): the COP is decomposed in two components: *rambling* which is the reference point migration (a method is provided to compute it from the COP) and *trembling* which is the center of pressure migration around the reference point (COP minus the rambling trajectory). Rambling is very similar to the gravity line and has lower frequencies and larger amplitudes than trembling. Trembling is related to "*apparent intrinsic stiffness*" and is very similar to the COP-COG difference (neuromuscular response). These functional differences make these decompositions interesting options to make more sense of postural control analyses.

1.3.2. Postural control and emotions

The functional role of emotions as action dispositions is now well established (Frijda 1986). Similarly, the ability to stand upright on two feet is considered as a precursor to the initiation of other activities. This section review studies investigating the association between postural control and emotions.

Emotion perceptions and expressions involve distinctive patterns of muscle activations confirming the functional link between emotional reactivity and postural responses (Huis In 't Veld, van Boxtel, and de Gelder 2014). Affects' impact on postural control is a relatively new field of research in the motor control domain (Horslen and Carpenter 2011). Participants are usually standing on a force plate while pictures designed to elicit emotions are displayed in front of them. Databases of emotional pictures such as IAPS are commonly used (P. Lang, Bradley, and Cuthbert 2008). Hypotheses about the impact of emotions on body signals are often driven by motivational theories (P. J. Lang, Davis, and Öhman 2000) or the action tendency component of appraisal theories (Frijda 1986). Negative or threat stimuli can trigger flee behaviors, fight behaviors or freezing behaviors (Hagenaars, Stins, and Roelofs 2012) (Hagenaars, Oitzl, and Roelofs 2014). Positive stimuli might elicit an approach behavior or induce a ''do anything'' motor program (Gross, Crane, and Fredrickson 2010).

Freezing, studied for decades in animal studies, has recently gained increasing interesting human postural studies. It has several evolutionary advantages: avoiding detection, optimize attention and prepare for rapid escape (Hagenaars, Oitzl, and Roelofs 2014). Postural freezing behaviors are usually detected in the center of the pressure signal, which shows a decrease in amplitude and an increase in frequency (Azevedo et al. 2005), (Facchinetti et al. 2006). Authors interpret it as a more stiff posture resulting from two mechanisms: increased muscular co-contraction and tighter anticipatory (or feedforward) control (Stins, Roerdink, and Beek 2011). However, to date no studies proposed the analysis of the COP-COG decomposition for the understanding of this phenomenon (Winter et al. 1998). Results from (Horslen and Carpenter 2011) suggest that this increase in frequency is modulated by arousal. Freezing is also associated with bradycardia (i.e. reduced heart rate) as in (Hagenaars, Roelofs, and Stins 2013) where freezing was associated with reduced heart rate and sway path length. Another way to investigate postural control processes is to analyze the dynamic structure of COP fluctuations (e.g. sample and approximate entropy): it gives indications about the "*regularity*" of the signal (Stins, Roerdink, and Beek 2011). Results available about the type of COP displacement (in the two axes: Anterior-Posterior AP or Medial-Lateral ML) for the study of approach and avoidance behaviors are less consistent (Roelofs, Hagenaars, and Stins 2010). (Horslen and Carpenter 2011) argue that methodological issues are responsible for these inconsistent results such as sampling duration. Another limitation of such studies is that they do not consider ecological nor interactive situations. Also, individual differences are not considered which might hide specific effects on postural control. Another line of research consists in evaluating the influence of emotions on directional movements where it is hypothesized that approach-avoidance strategies are more visible. Classical paradigms are tasks where participants must do a step forward, or lean in a specific direction (Fawver et al. 2012). Interestingly, only two studies investigated body sway in response to affective facial expressions. (Roelofs, Hagenaars, and Stins 2010) did not find directional pattern such as approach or avoidance responses to any facial expressions. Instead, they found that angry faces induced significant reductions in body sway as compared with neutral faces and happy faces, this result being interpreted as a freezing response. Recently (Gea et al. 2014) found both happy and pain faces elicited greater postural sway of the body in the anterior–posterior axis compared with neutral faces. Also, both happy and pain faces elicited increased amplitudes of forward body movements corresponding to an approaching pattern of body sway (recorded by a webcam). Authors interpreted these two results with the same interpretation: these cues were relevant for delivering effective care and social support.

To our knowledge, no study investigated the impact of the perception of bodily emotion expression on the postural response. Two studies showed a postural contagion phenomenon when participants were facing a human representation of postural imbalance, both in the AP and ML plane (Tia et al. 2011), (Tia et al. 2012).

1.3.3. Postural control in conversations

Posture mirroring and synchrony within conversation between strangers is not a recent research domain (Condon and Osgton 1971), (France and Ickes 1981). Until recently, methods of behavior recording were gross and subjective (hand coding strategies). Some methods such as stick figures tracing provided remarkable results about coordinative structures but were few because of their time consuming properties (Newtson 1994). Authors identified "*behavior waves*" occurring within conversations between strangers. More recently, (Shockley, Santana, and Fowler 2003) used modern methods of quantification of postural dynamics to measure postural coordination. The rationale behind the idea that body sway of both participants might be coordinated is that postural stabilization is not an "*end goal process*" but a "*facilitator of the goal of suprapostural activity*". The center of pressure has to constantly adjust to required center of mass changes. With conversation considered as a suprapostural task which involves listening, gesturing and visual inspection, they investigated the coordination pattern within a puzzle task involving conversation. In a subsequent study, they replicated their findings and described the interpersonal coordination as emerging structures (Shockley, Richardson, and Dale 2009). In this line of research, a recent study evidenced that movement constraints during a

cooperative conversation impaired postural coordination which in turn impacts the communication process and the relationship (Tolston et al. 2014).

Other studies investigate social postural coordination in more control setup such as in phase body leaning (Varlet et al. 2011). Although interesting on a theoretical point of view, these studies are difficult to generalize to more ecological setups such as in (Shockley, Santana, and Fowler 2003) and are therefore not reviewed here.

1.4. Conclusion

This review of the literature related to the case study appears to be complementary to our initial state of the art. While in chapter 2 we undertook a detailed review of interpersonal processes in general, and their related individual differences, the review made here provides us with a clearer picture of the special task of a job interview. Job interviews are highly stressful situations eliciting a large range of negative emotions as a function of the individual appraisal of the situation. This non-affiliative context is particularly important in the study of interpersonal processes as it has been shown to impair spontaneous coordination. Relevant to this study is the absence of works about the low level interactive nature of a job interview from both Human Sciences and Computer Sciences. In Human Sciences, studies focus on the analysis of high level coping strategies and physiological reactions to the task as a stressor without going into the detailed analysis of the interaction at a micro level. In Computer Sciences, some recent works propose promising insights into the design of interactive virtual judges, but none of them attempted to analyze and model interpersonal processes such as behavioral matching and interactional synchrony. Instead, they focus on more individual phenomena such as the inference of user's emotion states.

The second point tackled in this review pertained to nonverbal behaviors particularly relevant for the job interview task: listening behaviors (judges are listening in our case study) and postural control (participants are standing in our case study). Listening behaviors, also called backchannel, have been the subject of a prolific literature in Computer Sciences providing a stable ground on which to propose a listening virtual judge. However, one major limitation is the focus on head behaviors without consideration of postural movements. Very few Human Sciences works proposed to investigate these backchannel behaviors. In an opposite manner, postural control is the subject of extensive works in Human Sciences and particularly movement sciences and motor control. Postural control appears to be a dynamic and complex process tightly related to emotional experience and social interactions, in accordance with the theory that emotions are embodied in our tendencies to act and stand in the environment. As such, it appears to be a privileged channel to be analyzed in such a highly emotion interactive situation. In addition, this review provided us with a detailed methodology analysis for the study of postural sway. However, to our knowledge no study in Computer Sciences attempted to consider the dynamic role of postural control: the focus has been on the static configural aspect of postural changes.

Overall, this short survey highlighted an interdisciplinary interest in the task of job interviews. In addition, key elements of this specific task such as dynamic postural control or listening behaviors have been analyzed in different field providing us a solid ground on which to conduct our analysis.

2. RESEARCH APPROACH AND METHOD

2.1. Overview

The context of the collect of the job interview corpus was an interdisciplinary project about how individual cope with demanding situations given their individual profiles (COMPARSE). The protocol was adapted from the Trier Social Stress Test, a standardize protocol to induce stress from a job interview situation in psychological studies (Kirschbaum, Pirke, and Hellhammer 1993). Several multimodal variables were captured to fit each team interests.
One main constrained of the project was to respect a certain level of experimental ecology, thus preventing from the use of intrusive full body sensors such as motion capture suits. In order to have information about the participants' bodily activity, we added a force plate to the protocol (to record postural control) and a video camera (to record general bodily activity). The general bodily activities of the interviewers were also collected via a video camera. This chapter will focus on the nonverbal interaction based on the data extracted from these 3 devices only.

The adapted protocol includes several phases which are a reading phase (for audio calibration), an instruction phase, a presentation phase and a feedback (from the judges) phases. In order to reduce the scope of our research and to limit the phenomena at play in the social interaction (such as verbal exchanges), we will focus on the presentation phase.

The first of the following sections describes in details the collected corpus (limited to the description of aspects relevant for this PhD thesis). With this description, we provide two preliminary analyses which aim at validating the impact of the task as a stressor and the usefulness of the force plate compared to video based extraction techniques for the analysis of postural control. We then present two different approaches to the analysis of the corpus: at the individual level (only the participants' data are analyzed) and at the interactional level (participants and judges data are analyzed together). In both, a special interest will be given to the influence of individual differences. Also, the individual analysis will investigate the evaluation and prediction of perceived task performance, a key element in order to help participants improve their nonverbal presentation. Encouraged by the result from these two parts, we present in the subsequent section the first steps toward the development of a virtual judge which could reproduce the subtle interactive patterns emerging in the job interview. The minimalist nature of the proposition aims at fitting both the objectives of an application driven development (to engage the user in a believable interaction) and an experimental driven development (to reproduce the reality in order to investigate it further in a controlled and systematic way). Lastly, we conclude this chapter and propose some perspectives.

2.2. Hypotheses

In chapter 2 and 3 we draw several general hypotheses about how individual differences might be associated with interactional synchrony. Some modulations should be made for the specific context of the job interview task: being under the judgments of two assessors, participants experience more or less negative affects. Also, the presence of negative affect is thought to impair non-conscious synchronization by enhancing the tight control of movements and limiting the apparition of spontaneous social heuristics. Thus, we discuss potential hypotheses for each selected individual differences regarding this additional effect of emotion:

- Neuroticism: This trait is directly associated with self-esteem itself tied to the way to appraise others' judgments. Being more neurotic lead to low self-esteem which leads to increase fear of rejection and social anxiety. As such, we expect neuroticism to be related to less spontaneous synchronization due to its association to negative feelings. The effect of negative emotions might also have an influence on individual postural behavior, inducing a more rigid control of movements (higher frequencies and lower amplitudes).

- Alexithymia: In our general hypothesis, we supposed that alexithymia might be associated with lower quality of interpersonal coordination via an impaired ability to delay reactive behaviors, in particular emotional reactions (e.g., personal distress). In the job interview, this effect might interact with the general effect of negative emotions: more alexithymic individuals will be more overwhelmed by their emotions and therefore less subjects to spontaneous synchrony. At the individual level, an effect similar to neuroticism might be observed (higher frequencies and lower amplitudes).
- Agreeableness: In our general hypothesis, we supposed that agreeableness might be associated with greater quantity of interpersonal coordination via a greater motive to affiliate with others. However, the job interview task is a totally non-affiliative task: there are little reasons why an individual might be motivated unconsciously to assessors. Thus, we hypothesis that the agreeableness will not be associated with any synchronization variables.
- Extraversion: In our general hypothesis, we supposed that extraversion might be associated with greater leadership in the interpersonal coordination via a greater sense of agency. This effect of leadership is relevant in task where some uncertainty exist in the initiation of action: both members of a dyad might perform a movement. In the job interview task, we focus on the presentation phase which fixes the respective role (talking participant and listening judges) which does not enable the study of initiatives. Thus, we do not expect to evidence a link between extraversion and leadership in this task. However, extraversion is associated with enhanced positivity, a feeling associated with a general trust in others. Alternatively put, more extrovert individuals are less prompted to perceived ego-threat in others' eyes. Leading to less negative affect, we hypothesize that extraversion is associated with more spontaneous synchrony (in this specific context).

3. CORPUS: COMPARSE

This section present the collected corpus and how the protocol adapted from the Trier Social Stress Test, a standardize protocol to induce stress from a job interview situation (Kirschbaum, Pirke, and Hellhammer 1993).

3.1. Participants

43 university students volunteered to participate in the study. They were 19 males and 24 females. Mean age of male students was 23.9 years± 4.4 (mean ± SD), body weight: 76.3 kg ± 10.1; height: 179.6 cm ± 10.1. For the female participants, the mean age was 28.2 years ± 9.9, body weight: 63.0 kg ± 10.4; height: 166.9 cm ± 8.6. They were free of sensory, perceptual, and motor (shoulder, elbow, hip, knee and ankle) disorders and naïve about the purpose of the experiment. The corpus was constituted in 3 different sessions as described in Table 17.

Session date	Number of participants	Women / Men	Mean Age
2012.05.30-31	19	12 / 7	27
2013.04.05	10	6 / 4	26
2013.06.18-19	14	6 / 8	26
Total	43	24 / 19	26,3

Table 17: Description of the 3 sessions which constitute the COMPARSE corpus

In this thesis, four analyses are run on subgroup of this corpus:

- COMP1 is composed of 19 participants from the first session (7 males and 12 females, mean age was 26 years± 6.1). Two participants' data were lost due to force plate malfunction bringing COMP1 to 17 participants. The first two analyses (protocol validation and comparison of COG signals) are done on this subgroup.
- COMP2 is composed of 43 participants from the three sessions (19 males and 24 females, mean age was 26.4 years± 4.1). Twelve participants are not considered because of missing data in one of the three used device (force platform, video camera on participant and video camera on assessors) bringing COMP2 to 31 participants. The last two analyses (behavioral analysis of the presentation phase and interaction analysis of the presentation phase) are done on this subgroup.

3.2. Measures

The COMPARSE corpus is the result of a collaborative project. Various measures have been used to capture a wide range of variables. In the scope of this thesis, only relevant measures are presented. More complete presentations of the measured variables are presented elsewhere (Giraud et al. 2013).

3.2.1. Personality questionnaires

Several individual differences were collected in this corpus. For the purpose of this PhD thesis, we select only the questionnaires related to the model we proposed in Chapter 2 and 3: the Five Factor model of personality (Costa and McCrae 1992) and the Toronto Alexithymia Scale (Bagby, Parker, and Taylor 1994). The Five Factor model of personality is the most widely used and extensively researched model of personality. It is a hierarchical model of personality traits with five broad factors: Extraversion (E), Agreeableness (A), Conscientiousness (C), Neuroticism (N), and Openness to experience (O). The French version (Big Five Inventory Francais; (BFI-Fr) (Plaisant et al. 2010)) is a 45-item questionnaire scored on a 5-point scale. As explain at the end of Chaper 3, we will focus on extraversion, agreeableness and neuroticism given their theoretical associations with our hypotheses. Alexithymia was measured by the 20-item Toronto Alexithymia Scale (TAS-20; French version: (Loas et al. 1997)). It is an inventory consisting of 20 items on a 5-point Likert scale which assess a general deficit in experiencing and processing emotions. The scale measures three dimensions of the construct: Difficulty Identifying Feelings (DIF), Difficulty Describing Feelings (DDF) and External Oriented Thinking (EOT). As explain in Chapter 3, we will focus on the affective component of emotion regulation composed of DIF and DDF.

3.2.2. Affect questionnaires

Emotional states were measured at two times during the experiment (before and after the task) with two questionnaires. State anxiety was evaluated by The Spielberger's State Trait Anxiety Inventory (STAI-S) (C. D. Spielberger, Gorsuch, and Lushene 1970); French version:(Charles Donald Spielberger, Bruchon-Schweitzer, and Paulhan 1993)). For the assessment of current mood states, we used the widely used Positive and Negative Affect Schedule (PANAS; (D. Watson, Clark, and Tellegen 1988); French version: (Gaudreau 2000)). The scale consists of two 10-item scales rated on a 5-point Likert for the Positive Affect (PA) and Negative Affect (NA), respectively.

3.2.3. Physiological measures

The Autonomous Nervous System (ANS) is known to be closely associated with participant's arousal (Boucsein 2012). Thus, four kinds of ANS variables were recorded during the session: electrodermal skin conductance (SC), skin blood flow (SBF), skin temperature (ST), cardiac rate (instantaneous heart rate (IHR), and heart rate variability (HRV)).

These variables were recorded on the left hand of the participant (SC, SBF, and ST) and on the chest (IHR, HRV). These physiological measures will only be used to evidence the validity of the protocol in eliciting stress related states, but won't be considered in the analysis of body related behaviors.

3.2.4. Collected behaviors

Participants' behaviors were recorded by five devices (Figure 43). Here we report about collected behaviors related to the body channel only. Whole body behaviors were recorded by one Sony HDR-CX550 camera at 25fps in full HD. Postural control was recorded with an Accugait AMTI force plate at 50Hz. The force plate was hidden within a stage covered by a blue sheet. A similar blue sheet was also placed on the wall behind the stage to provide a uniform background. Participants were asked to stand close to a white cross in the middle of the force plate. Seated assessors' behaviors were recorded with a Sony HDR-CX550 camera. Videos and force plate data were synchronized manually according to two time markers: a kick on the ground and a clap with hands. In opposition to a motion capture setup, these devices enable to capture many type of information while keep the ecological validity of the setup high.

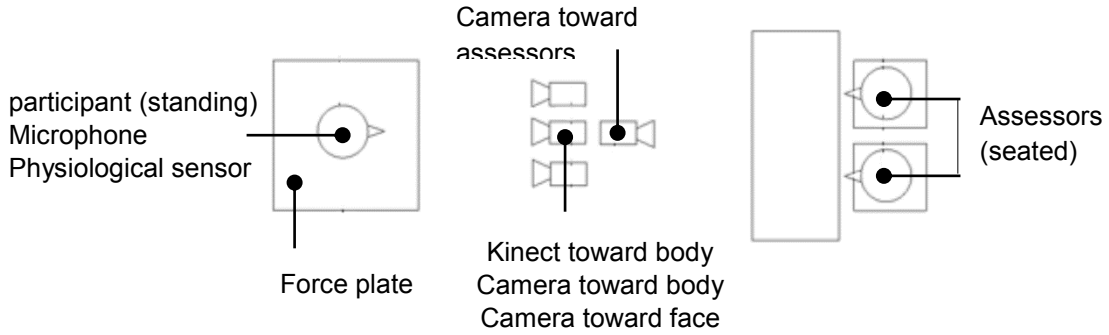

Figure 43: Top view representation of the setup organization

3.2.5. Task performance

In the aim of building a virtual judge to help individuals manage interview sessions, it is important to provide a measure of the performance on the task. To do so, we use two complementary analyses. First, we asked four raters to assess the performance of each presentation from COMP2. Out of the various possible indicators of what is a good performance in public speaking, we focus on "perceived discomfort" (similar to stressed) and "perceived motivation" (similar to engagement) as they have been found to be related to positive evaluations and associated with bodily behaviors (Fydrich et al. 1998). Each dimension was evaluated on a 5 points likert scale. To further concentrate on nonverbal behaviors, the videos of the presentations are presented without sound (remove the impact of the content of the speech). In a training phase, the four raters evaluated three presentations not present in COMP2. After discussing their results to refine their common understanding of the two scales, they evaluated the entire corpus. Internal consistencies is adequate for discomfort (alpha = 0.69) and good for motivation (alpha = 0.76). A second approach was to directly ask participant of the public speaking task to assess their own performance. In this thesis, two of the nine questions from (Baggett et al., 1996) are considered: motivation (how they felt motivated during the task) and stress (how they felt stressed during the task). These questions were translated into French language. A first investigation reveal no significant correlations between observed and self-reported motivation ($r = 0.183$, $p=0.342$) and observed and self-reported discomfort ($r=-0.257$, $p=0.177$). This discrepancy highlights the relevance of considering the gap between felt and perceived performance.

3.3. Procedure

Ethical issues call for a simulation of the job interview rather than recording real job interviews. Thus, the instructions that we defined and provided to participants were as follows: "*You are applying to a job that is particularly important to you. You will have five minutes to present yourself in front of a camera and describe your personal characteristics (e.g. personality, skills, and experiences) that you view as strengths and that would allow you to be relevant for this job. You must also indicate those characteristics that might be perceived as weaknesses and how you did or are willing to improve them. Be as sincere as possible. This is an important prerequisite for this position.*"

Figure 44 summarizes the steps in the experiment. After physiological and psychological measures were collected before the task, the participant entered the experimental room and stood in front of the camera. The room was sound attenuated and light kept constant throughout the experimental session. After two-minute reading and five-minute speaking, two judges started to provide feedback about the performance of the participant and asked questions. The first judge provided a negative feedback. The second judge provided a positive feedback. This order was selected for ethical reasons: the sessions ended on a positive feedback so as to avoid leaving the participant in a negative mood. Gender of jury providing negative feedback was counterbalanced across participants. Before leaving the experimental room, the participant was asked to rate his own performance on a scale along with his current emotional state and coping strategies. The participants was thanked for his participation and allowed to leave the experiment room. The participant was debriefed and was interviewed by a psychologist to ensure he left the lab in a positive state.

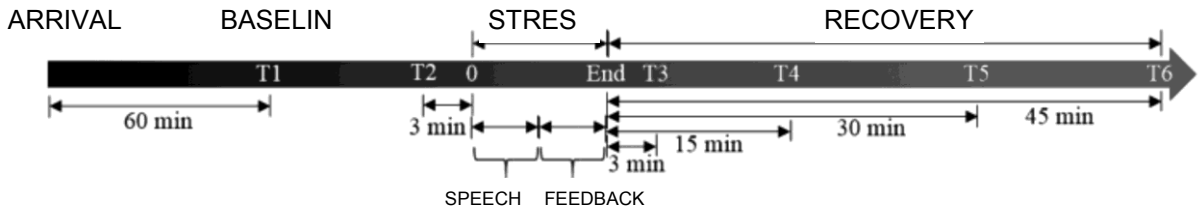

Figure 44: Experimental timeline from (Hua et al. 2014). T1: Saliva Sample 60 min after arrival at the laboratory; T2: Saliva Sample 3 min pre-test; pre-task subjective emotional states ; sensors calibration; T3: Saliva Sample 3 min post-test; post-test subjective emotional states; T4: Saliva Sample 15 min post-test; T5: Saliva Sample 30 min post-test; T6: Saliva Sample 45 min post-test.

For the purpose of this thesis, data will be analyzed on for the presentation phase (speech) to concentrate on one type of asymmetrical interaction: participant standing and speaking and judges seated and listening.

3.4. Protocol validation

The protocol validation has been done on COMP1. We analyzed physiological measures to assess if the task has been experienced as a stressful situation as compared to a baseline. We chose three ANS relevant variables. Heart rate is a measure known to increase in stressful situations (Johnson et al. 2011). Another relevant measure is the skin temperature which is known to decrease at extremities during stressful situation as a consequence of vasoconstriction (Boudewyns 1976). Finally skin conductance is also known to increase as arousal increases (Tomaka et al. 1993). For each variable, we applied a dependent t-test (parametric test for paired samples) to compare the means of the baseline condition and the task condition (values averaged for the reading, speaking and questions sessions). Heart rate did significantly increased ($t(18) = -10.208$, $p < 0.0001$), skin temperature did significantly decreased ($t(18) = 4.827$, $p < 0.0001$) and skin conductance did significantly increased ($t(16) = -2.383$, $p < 0.05$) . Together, these physiological measures show a significant impact of our protocol on the participant state as it has been traditionally shown with the Trier Social Stress Test (Kirschbaum, Pirke, and Hellhammer 1993).

Secondly, we tested differences in self-reported affect states and anxiety between the measures before and after the task. Three Wilcoxon signed-rank tests (nonparametric test for paired samples) showed no significant differences between the two times for negative affects (NA, Z=-0.476, p=0.634), positive affects (PA, Z=-1.209, p=0.227) and anxiety (STAI-S, Z=-1.876, p=0.061). These results show that participants were in the same state before and after the task. As physiological measures showed, this is not due to a non effect of the task on participants' state. This might be due to the fact that participants' states were collected just before and just after the task. Thus participants could have been anxious at both moments. Another reason could be our choice to not counterbalance the two feedback sessions: finishing by positive feedback ensures a diminished residual negative experience at the end of the session. A last reason could be that they were unaware of both their emotional states and associated physiological changes.

Findings from emotional and anxiety states showed no differences before and after the task which is an ethical necessity. Also, the first results provided about physiological measures showed a significant impact our protocol on the participant activation suggesting that it succeeded to induce stress.

3.5. Participant bodily behaviors processing

One approach to the analysis of nonverbal behaviors in Computer Sciences is to compute a large range of low level features in order to explain as much variance of the collected corpus and to predict a dependent variable (e.g., emotion labels or task engagement). The issue of this approach is that it maximizes the performance of the predictive algorithm at the expense of the interpretability of the results. In order to keep a high level of interpretability, we compute bodily variables identified in the literature to have predictive and explanatory power.

3.5.1. Postural control

The force platform on which the participants stand provides us the Center Of Pressure (COP) displacements in the two axes: Anterior-Posterior (AP) and Medial-Lateral (ML). To obtain a more detailed analysis of the postural control process, we decompose each signal into two signals: the Center Of Gravity displacements and the difference between the COP and the COG (indicator of postural stiffness) following the method proposed by (Olivier Caron, Faure, and Brenière 1997). Considering that the body sway can be modeled as a one-link inverted pendulum where COG and COP behave as periodic functions in phase with each other, they established a relationship in the frequency domain between the relative amplitudes of the oscillations of the COP and the COG (equation 1-5).

$$\text{Eq. 1 :}\ \frac{COG}{COP} = \frac{\omega_0^2}{(\omega_0^2 + \omega^2)}$$

$$\text{Eq. 2 :}\ \omega = 2\,\pi\,f$$

$$\text{Eq. 3 :}\ \omega_0^2 = \frac{mgh}{(I_G + mh^2)}$$

$$\text{Eq. 4 :}\ IgML = 0.0572mH^2$$

$$\text{Eq. 5 :}\ IgAP = 0.0533mH^2$$

Where f is the pulsation in (rad s^{-1}), ω_0 the natural body frequency, m the mass of the participant, g the gravity acceleration, h the distance from COG to the ground, I_G the moment of body inertia around the ML or AP axis and H the height of the participant. As shown in equations 1 – 5, it necessitates knowing only three anthropometric values: height, weight and the height of participants to compute COG from COP data. Height and weight were asked to participants and gravity center height fixed for male (57% of the height) and female (55% of the height) according to anthropometric tables (Winter 2009). From these equations, the COG calculation consist in multiplying the data transformed in the frequency domain, acting as a low pass filter. This process is performed on both AP and ML plane separately, resulting in the extraction of four times series (COG AP, COG ML, COP-COG AP, COP-COG ML). Figure 45 presents an example of the time series resulting from this decomposition process.

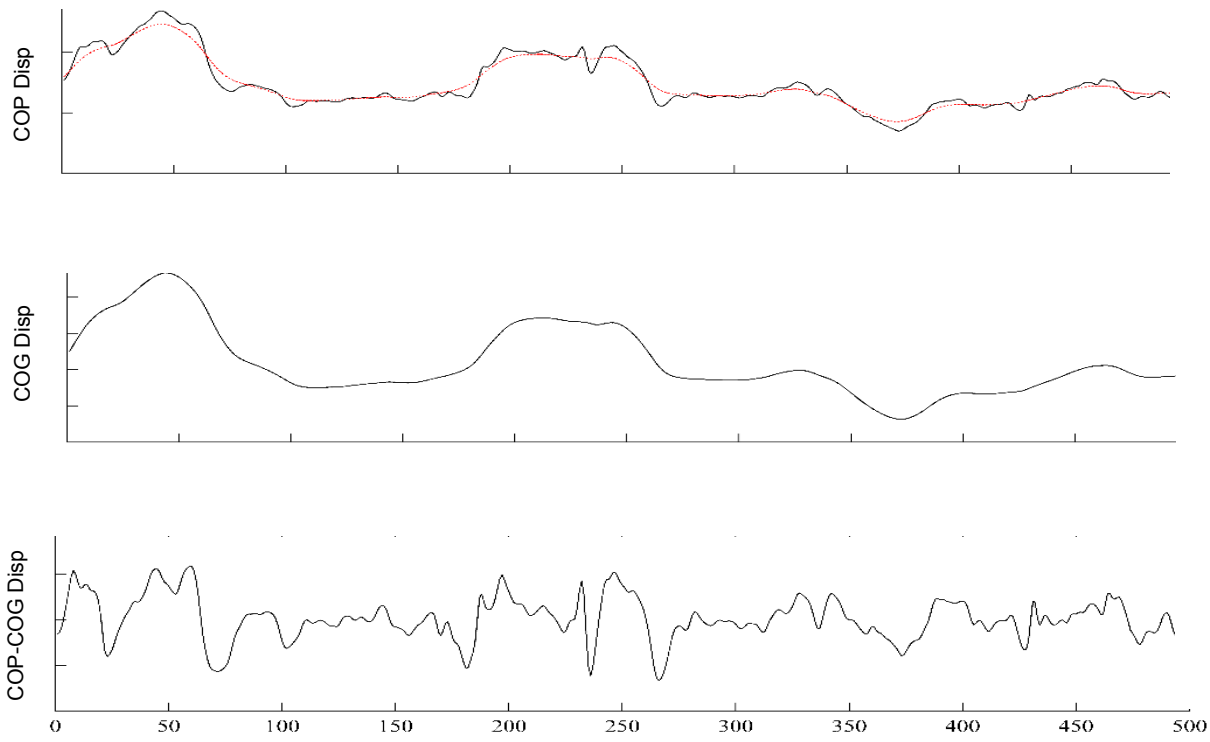

Figure 45: COP displacement (a) is filtered with the (Olivier Caron, Faure, and Brenière 1997) method to obtain COG approximation (b), subtract COG from COP to obtain the residual neural motor response (c).

In addition to these four time series, we computed the two dimensional instantaneous speed from AP and ML COP. This variable has been found to be complementary and consistent across repetitions (Duarte and Freitas 2010). Table 18 summarizes the five time series acquired. From each time-series, global characteristics features are computed. While these features can be numerous, we aim at keeping our result interpretable and focus on relevant features from the literature. In our case, mean of displacement is not of interest as it represents the absolute position on the force plate. We are rather interested in characterizing the variability of the displacement which can described via temporal features (standard deviation or root mean square) and frequential features (mean power frequency or frequency peak)(Duarte and Freitas 2010). For the four time-series of displacement, we compute standard deviation (SD) and mean power frequency (MPF). Complementarily, a 2D global measure of displacement variability is the confidence ellipse which is an ellipse within which is included 95% of the body sway. Finally, we compute the mean for COP speed.

Time series	Global statistics	
COG AP	SD, MPF	Confidence ellipse
COG ML	SD, MPF	
COP-COG AP	SD, MPF	
COP-COG ML	SD, MPF	
COP speed	MEAN	

Table 18: Time series variables and their corresponding global statistics for postural control

3.5.2. Global movements

The RGB camera facing the participant provides us information about the global movement activity. Using computer vision algorithm, it is nowadays possible to extract various expressivity features relevant for the study of bodily expressivity (Camurri, Lagerlöf, and Volpe 2003).

We extracted two variables from the video stream: the Quantity Of Motion (QoM) and the Contraction Index (CI). The contraction index is the degree of contraction of the body in the 2D plane of the camera. It is computed by comparing a bounding box that cover the human silhouette with the area covered by this silhouette (Castellano, Villalba, and Camurri 2007), (Bonardi, A., I. Truck 2006). The human silhouette is segmented using a background subtraction algorithm. Since our background is static, we use a simple background subtraction algorithm that calculates the absolute frame difference between a reference empty scene and the input image that contain the performer. In order to provide more robustness to variable lighting conditions and shadows, the background subtraction algorithm is computed using the HLS space similarly to the method proposed in (Yoo, Hwang, and Moon 2009). The quantity of motion is the total amount of displacement in the 2D plane of the camera. It is often considered as a measure of the kinetic energy. We use the motion history images algorithm (MHI) (Davis and Bobick 1997) that provides an image template that shows the recency of motion in a sequence.

$$\text{Eq. 6 : } CI = \frac{As}{Cs}$$

$$\text{Eq. 7 : } QoM = \frac{QoP}{Cs}$$

Where *As* is the area of the silhouette (in pixels), *Cs* the area of the bounding box surrounding the silhouette and *QoP* is the quantity of pixels moving in the image. In addition to these two variables, we computed the first derivative of the quantity of motion which provides us some information about the temporal perturbation of the motion regime. This first derivative of QoM is often considered as a measure of impulsivity (Camurri, Mazzarino, and Volpe 2004). For each of these three expressive dimensions, we compute the mean, standard deviation and mean power frequency as global statistics (Table 19).

Time series	Global statistics
CI	MEAN, SD, MPF
QoM	MEAN, SD, MPF
Impuls	MEAN, SD, MPF

Table 19: Time series variables and their corresponding global statistics for global movements

3.5.3. Complementarities of the two measures

Forceplate are costly sensors. The COG component of the COP can be extracted from low cost cameras via silhouette extraction techniques or by led diode located on subject's head (Gea et al. 2014). As one of our goal is to contribute to the design of system for non-laboratory situation (job interview training applications), it is of primary interest to know to which extent the force platform device is useful compared to cameras. Therefore, we conducted a preliminary study (on COMP1 corpus) which aimed at comparing the center of gravity extracted from the force plate and the center of gravity extracted from the RGB video camera (it is impossible to compute inertial reaction forces from a RGB camera). This study was conducted only in the Medio-Lateral plane as no camera was positioned to extract the Anterior-Posterior plane.

We calculated the center of gravity signal in the ML plane from the center of pressure signal with the method described in the previous section. For each video sequence, we computed the center of gravity for each participant. This center of gravity is computed directly from the human silhouette. The human silhouette is segmented using a background subtraction algorithm as described in the previous section. After the foreground silhouette is obtained, the center of gravity point $C_g = (x_g, y_g)$ is obtained by computing the following equation (Dedeoğlu et al. 2006):

$$\text{Eq. 8 : } x_g = \frac{\sum_i^N x_i}{N}, \qquad y_g = \frac{\sum_i^N y_i}{N}$$

Where N is the number of pixels in the human foreground silhouette. Figure 46 shows an example of an extracted human silhouette and the estimation of its corresponding center of gravity.

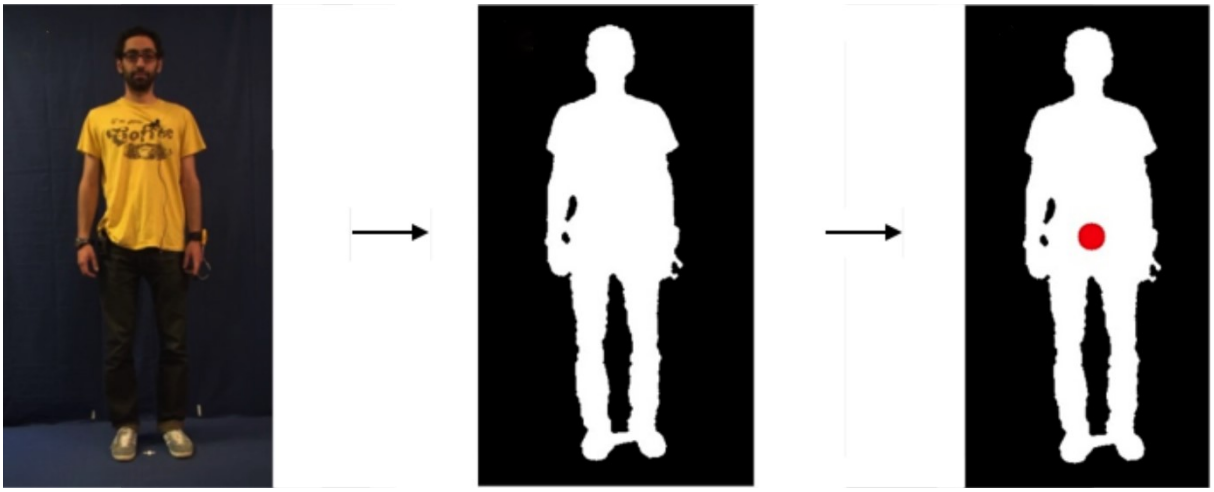

Figure 46: The COG extracted from the human silhouette. The images are, respectively: (a) the captured image, (b) the extracted silhouette and (c) the COG represented by a red circle.

To compare the obtained time-series, we first computed the correlations between the COG from the video and from the force plate to evaluate the shared variance in the temporal domain. Table 20 shows averaged correlations between the COG time series from the force plate and video for each task phase. For all phases, correlations were very strong and significant ($r > 0.85$, $p<0.001$). A Kruskal-Wallis test (data are not normally distributed) revealed no statistically significant difference between the experimental phases ($chi^2(4) = 2.343$, $p = 0.673$).

	Phases of the public speaking task					
	Read	Listen	Presentation	Negative Feedback	Positive Feedback	Total
	N = 17	N = 17	N = 17	N = 17	N = 17	
r	0.889	0.937	0.879	0.911	0.856	0.894
sd	0.083	0.046	0.125	0.090	0.156	0.100

Table 20: Pearson correlations between COG time series from video and force plate (n = number of sequences)

The majority of the COG signal from the force plate is present in the COG video signal (total $r^2 = 80\%$). The lost variance might be due to noise in the video extraction process. Sources of noise for video processing include loose clothes, silhouette artifacts due to shadows and asymmetric occlusions. Another potential source of lost variance is the resolution of the video recordings. As the camera is placed three meters from the participant, one pixel of the silhouette represents approximately two millimeters of the silhouette.

In the human body sway, there is a relation between COG displacement amplitude and frequency range (Stins, Roerdink, and Beek 2011). Relatively high frequencies represent small amplitudes and vice versa. These small amplitude displacements might represent a small portion of variation in the temporal domain, but still having a strong impact on the power frequency spectrum. As most balance studies use frequency variables to describe postural control, it is important to know if COG signals extracted from videos are sensitive to only low frequencies due to low resolution.

In the frequency analysis, only data from sequences with hands free are used (all but the reading session). A COP signal is composed of very low frequencies (under 0.05 Hz), which are sensitive to signal length. In fact, 1/T (T being the sequence length) determines the lowest frequency represented by a Fourier transform (FFT). For this analysis,

frequency spectrums are presented only for a fixed window [1/Tmin, 1] Hz, where Tmin is the smallest length of our sequences (Tmin = 37 s, lowest frequency represented = 0.027 Hz).

For each sequence, power spectral density (PSD) of COG from video (COG video), COG from force plate (COG FP) and COP from force plate (COP FP) were computed with a FFT. The PSD were normalized with respect to the individual peak values of the PSD. These normalized data were then averaged for the group (Stins, Roerdink, and Beek 2011).

Figure 47 presents these three PSD from each signal. The graph suggests that the COG extracted from the video did not contained frequencies above to 0.2 Hz. As explained previously, this is probably due to the low resolution of the video recordings. COG and COP extracted from the force plate are more represented in higher frequencies between 0.2Hz and 0.8Hz. The fact that the COP included higher frequencies was expected given the fact that COG FP is calculated via a low pass filter on COP FP.

Figure 47: Normalized power spectrums of the COG from the video and the force plate and the COP from the force plate.

To investigate further the impact of these differences in spectrum broadness, we computed for the three PSD the average frequency bands that contain 80% of the spectral power (hereafter called F80). It is equivalent to computing the area under the curve which contains 80% of the signal. This measure is considered as the best measure to characterize spectrum broadness (Latash et al. 2003).

		F80 (n=63)		
		COG Video	COG FP	COP FP
	mean	0.146	0.224	0.437
	sd	0.066	0.088	0.338
COG Video	Pearson r		0.264	0.058
	p		0.307	0.826
COG FP	Pearson r			0.595 [a]
	p			0.012

Correlation is significant at the 0,05 level

Table 21: F80 for COG from the video and the force plate and cop from the force plate and their correlations

Table 21 shows the mean and standard deviation of F80. Wilcoxon signed-ranked tests were used to compare these F80 two-by-two (non-normality and dependent samples). All means were significantly different ($Z = -5.765$, $p < 0.001$ between F80 COG Video and F80 COG FP, $Z = -6.805$, $p < 0.001$ between F80 COG Video and F80 COP FP and $Z = -6.846$, $p < 0.001$ between F80 COG FP and F80 COP FP), which confirms the fact that the COG extracted from video contains significantly lower frequencies than data from the force plate. We then computed the correlations between each F80: only F80 COG FP and F80 COP FP were correlated significantly.

From these different results, we can conclude that most of the COG signal from the video shared with the force plate signal (80%) is located at frequencies under 0.1 Hz. This part of the signal represents large COG displacements. Subtle displacements at higher frequencies are not present in the video probably due to low resolution. This analysis has methodological implication for future studies investigating postural control. To study large displacements and their variability, video is a relevant option. However, when subtler variations are important, video seems to be not precise enough, which is the case when freezing behaviors are of interest. Freezing behaviors induces immobility (reduced

standard deviation) and rigidity (increased mean power frequency) (Facchinetti et al. 2006). A COG video estimation method may not be able to differentiate between quiet standing and freezing standing in front of a threat as frequencies above 0.2 Hz are essential. This analysis has several limitations, which can be addressed in future studies. This analysis has been done only for the medial-lateral axis; a study of the anterior-posterior axis is required to be able to generalize the analysis. The insensitivity of video to small variations in this study is probably due to low resolution. How placing the camera in a vertical configuration or using a 4K camera (3840 pixels × 2160 pixels) could increase this sensitivity is another question. Comparison of complementarities between COG and the quantity of motion variable could be investigated. Symmetric and vertical movements are not represented in the GOG, which makes it less sensitive to hand movements. For the purpose of this PhD thesis, it seems adequate to measure postural control related variables via the force plate and global movement features via the video.

3.6. Conclusion

In this section, we presented the collected corpora in the context of the COMPARE project. Two preliminary analyses were performed: the validation of the impact of the task as a stressor and the complementarity of video and force plate data. These preliminary studies were performed on a subsample of the total corpus (COMP1). The following of the analysis will use the full sample (COMP2) in order to investigate the bodily behaviors at the individual level (section 4) and the interactive level (section 5).

4. INDIVIDUAL BEHAVIORS

This section present the second step in the analysis which aims at studying how participants behave during the presentation phase of our job interview protocol at the individual level without considering the interactive nature of task. Of particular interest is the study of how bodily behaviors are related to individual differences, felt emotions and task performance. Although the general aim of this PhD thesis is to study the social interaction, the understanding of the individual behaviors in the context of a virtual judge application is of primary importance, particularly in the objective to provide feedbacks about the perceived performance.

As presented in the method of this section, task performance is composed by self-report of performance and perceptual evaluation of performance. In this chapter, we are more particularly interested in two different aspects of the performance: discomfort (or stress) and motivation (or engagement). These two dimensions are particularly relevant for the success of a job interview task and both have been conceived as highly embodied dimensions. We also include in the analysis the self-reported emotional states just before the task which might have a direct effect on task performance.

4.1. Individual differences, emotional states and task performance

We first looked at the associations between individual differences (“Extra” for Extraversion, “Agree” for Agreeableness, “Neuro” for Neuroticism and “Alex” for affective alexithymia as the composite of DDF and DIF), emotion states reported before the task (“sr_anxiety” for self-reported anxiety, “sr_posEmo” for self-reported positive emotions, “sr_negEmo” for self-reported negative emotion) and task performance indicators (“sr_motivation” for self-reported motivation, “sr_stress” for self-reported stress, “obs_discomfort” for observed discomfort and “obs_motivation” for observed motivation). Table 22 presents the correlations (Pearson) between these variables.

		Self-reported states			Task performance			
		sr_anxiety	sr_posEmo	sr_negEmo	sr_motivation	sr_stress	obs_discomfort	obs_motivation
Extra	r	-,503	,413	-,416	,258	-,181	-,284	,066
	p	,005	,026	,025	,176	,346	,135	,735
Agree	r	-,418	,367	-,139	,031	-,059	-,161	,062
	p	,024	,050	,472	,871	,763	,403	,749
Neuro	r	,383	-,491	,220	-,058	,149	,054	-,243
	p	,040	,007	,250	,764	,441	,781	,205
Alex	r	,380	-,305	,271	-,084	,348	-,163	-,029
	p	,042	,108	,155	,665	,064	,397	,882
sr_anxiety	r	1,000	-,698	,570	-,297	,281	,315	-,089
	p		,000	,001	,118	,140	,097	,647
sr_posEmo	r		1,000	-,200	,410	-,051	-,471	,411
	p			,299	,027	,794	,010	,027
sr_negEmo	r			1,000	-,150	,339	-,100	-,033
	p				,437	,072	,607	,866

Table 22: Pearson correlations between individual differences, task performance indicators and self-reported states before the task.

Individual differences were moderately related with reported emotions before the task, all the correlation being with the expected sign: extraversion and agreeableness have the same pattern (higher extraversion is associated with more positive emotions and less negative emotions) and neuroticism and alexithymia the opposite pattern. While the magnitude of correlation for self-reported anxiety and positive emotions are similar, self-reported negative feelings appear to be less strongly related to individual differences.

In terms of task performance, the pattern of associations is less clear. The only variable significantly associated with task performance is self-reported positive emotions, positively correlated with self-reported and observed motivation and negatively correlated with observed discomfort. Self-reported stress showed a tendency to correlate with affective alexithymia and self-reported negative emotions. Therefore, although the selected individual differences are clearly associated with the self-reported affective experience before the task, these variables seem less relevant to the experience of stress and motivation during the presentation task. One possible explanation is to consider that the selected individual differences are strongly related to the way individuals appraise the stressor task, which impact only partially the actual performance and resulting experience during the task.

4.2. Individual nonverbal behaviors

Our second analysis of how individuals present themselves in the job interview task pertains to the study of individual nonverbal behaviors. To do so, we computed the correlations between the extracted bodily variables and individual differences, self-reported states and task performance (Table 23).

		Individual differences				Self-reported states			Task performance			
		Extra	Agree	Neuro	Alex	sr_anxiety	sr_posEmo	sr_negEmo	sr_motivation	sr_stress	obs_motivation	obs_discomfort
SD_COG_AP	r	-,385	,189	,289	,065	-,025	-,044	-,221	-,040	,021	,147	,196
	p	,039	,326	,128	,739	,897	,822	,249	,835	,913	,447	,307
SD_COG_ML	r	-,362	-,034	,250	-,060	-,022	-,163	-,221	-,232	-,035	-,031	,434
	p	,054	,861	,191	,756	,911	,398	,248	,225	,857	,873	,019
SD_COP_COG_AP	r	-,104	,329	,056	-,136	-,202	,191	-,295	,241	-,166	-,106	,309
	p	,592	,081	,772	,483	,294	,321	,120	,208	,388	,585	,103
SD_COP_COG_ML	r	-,016	,067	-,213	-,192	-,224	,210	-,312	-,107	-,162	-,031	,390
	p	,935	,730	,267	,319	,244	,274	,099	,580	,400	,873	,037
MPF_COG_AP	r	,193	,019	-,022	-,211	-,082	,175	-,204	,202	-,261	-,071	,284
	p	,317	,921	,910	,272	,671	,363	,289	,293	,171	,715	,136
MPF_COG_ML	r	,261	-,018	-,489	-,406	-,046	,269	-,140	,211	-,285	,069	,244
	p	,172	,928	,007	,029	,813	,158	,470	,273	,134	,723	,202
MPF_COP_COG_AP	r	-,249	-,126	,129	,170	,336	-,327	,178	-,029	,300	-,162	,260
	p	,193	,516	,504	,377	,075	,083	,354	,881	,114	,401	,173
MPF_COP_COG_ML	r	-,349	,025	,184	,464	,317	-,237	,362	,191	,314	,069	-,303
	p	,063	,897	,340	,011	,094	,216	,053	,322	,098	,724	,110
MEAN_COPspeed	r	-,116	,249	-,006	-,147	-,161	,158	-,370	,218	-,236	-,083	,433
	p	,548	,192	,976	,447	,405	,412	,048	,256	,219	,668	,019
Ellipse_COP	r	-,441	,044	,216	,015	,017	-,106	-,234	-,106	-,089	,106	,421
	p	,017	,823	,260	,937	,930	,583	,221	,584	,645	,585	,023
MEAN_QoM	r	,103	,144	-,610	-,428	-,324	,427	-,274	,071	-,134	,493	,061
	p	,594	,455	,000	,021	,086	,021	,150	,715	,487	,007	,754
SD_QoM	r	-,114	-,040	-,214	-,134	-,156	,124	-,079	-,267	,261	-,047	,239
	p	,557	,836	,264	,488	,419	,522	,683	,162	,172	,808	,213
MPF_QoM	r	,161	,127	-,298	-,026	-,053	,080	-,038	,242	-,332	,538	-,281
	p	,404	,510	,116	,894	,783	,678	,846	,205	,078	,003	,140
SD_IMP	r	-,010	,073	-,363	-,222	-,260	,175	-,234	-,111	,016	,239	,106
	p	,960	,707	,053	,247	,173	,364	,221	,566	,935	,212	,583
MPF_IMP	r	-,083	,079	-,041	,074	,022	-,238	-,175	-,105	-,243	,184	,108
	p	,669	,682	,834	,702	,911	,213	,364	,588	,203	,339	,578
MEAN_CI	r	-,221	,012	-,095	-,018	,002	-,052	,020	-,096	,400	-,196	-,013
	p	,249	,950	,624	,928	,993	,790	,917	,620	,032	,307	,948
SD_CI	r	-,090	,109	-,050	-,128	,075	,126	,063	-,047	-,147	,440	,130
	p	,641	,573	,796	,507	,701	,515	,744	,809	,448	,017	,500
MPF_CI	r	,211	,041	,071	-,043	-,086	,111	-,040	,086	-,194	,075	,079
	p	,272	,832	,714	,824	,659	,567	,836	,657	,313	,698	,685

Table 23: Pearson correlations between individual differences, self-reported states before the task, task performance indicators and nonverbal variables.

The associations between bodily nonverbal behaviors and individual differences reveal an interesting pattern. Although a common hypothesis about extraversion is its association with greater activity, in our task extraversion is inversely related to postural movement amplitude (standard deviations and ellipse). Regarding extraversion, we previously built our hypotheses on the fact that more extrovert individuals, via their enhance trust in others, are less subject to negative emotions when judged by others. Following these interpretations, we expected to have the opposite pattern of a freezing stance: more amplitude and less high frequencies. Although extraversion was associated with less postural stiffness (MPF_COP_COG_ML) as expected, the postural variability was also lower (Ellipse_COP). We do not have a direct interpretation of such a result but alternative analysis might bring some light in this issue. In addition, neuroticism and

affective alexithymia have in common lower frequencies of macro oscillations of the COG and less movement quantity. In addition, affective alexithymia is associated with more postural stiffness (higher frequencies of COP_COG_ML). This pattern of decreased general movement quantity and large postural sway and an increase in postural stiffness seems very close to the definition of a postural freezing. Given the theoretical account of these two individuals' differences, two different interpretations can be drawn. Regarding neuroticism, its tight association with poor self-esteem might enhance the fear of rejection and the perceived ego-threat of the situation. Regarding alexithymia, the impossibility to manage the emotions inherently arising in such a task might lead to an overwhelming arousal level and a loss of control. In both cases, an instinctive behavior can be to freeze the posture. As expected, agreeableness was not related to any bodily variables.

Overall, the self-reported states and performance are not much related to bodily nonverbal cues. Punctually, more negative emotions at the beginning of the task is associated with low postural displacement speed and positive emotions with more movement activity. In terms of task performance, only self-reported stress was associated with more contracted movements. Perhaps these lack of associations is due to the fact that the self-reports are related to a more reflexive experience based on more cognitive aspects of the task such as the content of their speech rather than a more visceral feeling.

Lastly, the observed task performances show two interesting and different patterns of associations: observed motivation was associated with three variables of global bodily activity (overall quantity and frequency of movements, and variability of the contraction index), and discomfort was associated with four postural variables (variability of the center of gravity in the medio-lateral plane, variability of postural stiffness in the medio-lateral plane, speed of the displacement of the center of pressure and the confidence ellipse of postural movements). One interpretation of these findings is that raters based their judgments of motivation more on expressive movements (e.g., hand movement going with the speech) whereas they based their judgments of discomfort on less demonstrative cues such as postural movement assumed to be more spontaneous.

Together, these results provide an interesting base for a deeper analyses how individual differences, emotional experiences and observed performance could be associated. The selected individual differences were all associated with felt emotions before the task, probably reflected an impact on the appraisal process. However, these associations were not replicated for felt and observed stress and motivation during the task revealing a more complex pattern. Looking at bodily nonverbal cues, extraversion, neuroticism and affective alexithymia appeared to influence the bodily signature in such a stressful task in an interpretable manner. Self-reported states before and during the task had less consistent associations probably due to the nature of the measurement (conscious reflexive assessment). In contrast, observed discomfort and motivation had clear behavioral patterns, encouraging further development of this line of research. In sum, individual differences, felt emotional experiences, observed performance and bodily nonverbal behaviors are all related in a pair-wise way without being clearly articulated. A perspective of this work will be to propose a deeper review of the literature of the appraisal process to better understand how felt emotions are related to individual differences.

4.3. Prediction of observed task performance

As demonstrated in the previous analysis, the bodily signature of individual during a job interview provides information about its personality, emotions and is related to the perceived task performance in terms of discomfort and motivation. The last step of our analysis of individual behaviors in the presentation phase is to attempt to predict these observed motivation and discomfort. Providing such information at the end of a session could be useful in a training program of virtual job interviews in order to enable the individual to improve based on these feedbacks. This analysis is a proof of concept which can serve as the basis for a more comprehensive analysis of the issue.

As a preliminary analysis, we decided to build two separates predictors, each one composed of all significant or nearly significant variables from the previous analyses (feature selection). Table 24 shows a summary of the variables included in the two predictive models.

	Individual differences	Self-reported states	Nonverbal cues
Perceived motivation	ns	sr_posEmo	MEAN_QoM, MPF_QoM, SD_CI
Perceived discomfort	ns	sr_posEmo, sr_anxiety	SD_COGy, SD_COP_COGy, MEAN_COPspeed, Ellipse_COP

Table 24: Variable selection for the construction of the two predictive models.

Table 25 shows two simple regression analyses on the whole data. For the two models, we run the regression analysis with self-reported states alone, nonverbal cues alone and all predictors together. In both cases, the combination of self-reported states and nonverbal cues provided the best results: 59.2% of variance explained for perceived motivation and 47.3% of variance explained for perceived discomfort. Also, self-reported states equally explained perceived motivation and discomfort, nonverbal cues were much better at predicting perceived motivation (54% of explained variance instead of 28%).

	Self-reported states		Nonverbal cues		Both	
	R^2	p	R^2	p	R^2	p
Perceived motivation	0.176	0.019	0.541	0.000	0.592	0.000
Perceived discomfort	0.165	0.080	0.282	0.063	0.473	0.011

Table 25: Results of two linear regression analyses for the prediction of perceived motivation and discomfort.

We further tested the predictive power of a linear regression model by running a standard machine learning experiment: we run two different regression approaches (classical linear regression and support vector regression) using a 10-fold cross-validation procedure. This analysis is run via the machine learning application WEKA 3.6. Table 26 shows the resulting explained variance and Root Mean Square Errors. Consistent with the previously performed linear regressions, perceived motivation was better accounted by self-report states and nonverbal cues. Additionally, this more constrained cross-validation procedure reduced by half the explained variance revealing the high risk of over-fitting when using the whole sample.

	Linear regression		Support vector regression	
	R^2	RMSE	R^2	RMSE
Perceived motivation	0.325	0.656	0.369	0.637
Perceived discomfort	0.164	0.741	0.228	0.663

Table 26: Results of two different regression approaches using a 10-fold cross-validation procedure.

Several limitations of our approach should be acknowledged in order to assess the potential of these results. In addition to the limited sample size (n=31), the perceived performance measures show relatively low score reliability (Cronbach alpha around 0.7) which means that a large part of the measured variance is due to random measurement errors. As explained by (Kline 2011), "*poor reliabilities reduces the power of statistical tests; it also generally attenuates effect sizes below their true (population) value. Unreliability in the scores of two different variables, X or Y, attenuates their observed correlation*". Because the phenomenon (observed discomfort) is not accurately measured, it cannot be accurately predicted. One reason for this lack a reliability is probably due to the fact that discomfort and motivation impressions are multidimensional, caused by various nonverbal channels in an intertwined way. A next step toward a more accurate prediction of perceived discomfort and motivation would be to decompose this nonverbal channel to provide to rater a reduced amount of information. Some rater could observes faces only, others only the prosodic

channel, etc. By analyzing the separate contribution of each channel as well as their combination, a more effective prediction model could be built, less biased by measurement errors. Considering this limitation, the performances of our simple linear approach appear promising.

Another limitation of this approach in the long term goal of providing feedbacks about the perceived performance of the interviewee is that observations are made by external observers and not the interviewers themselves. To truly inform about the impact the presentation made to a judge, rating from judges should be collected. However, the difficulty to collect multiple ratings from judges of a presentation limits the development of such an approach.

Finally, this section about individual behaviors in the context of a job interview provides a base for a more in depth study and prediction of the role of bodily behaviors in the task performance. Future work will attempt to optimize the prediction workflow (from feature extraction/selection to machine learning algorithm optimization) as well as provide a sharper theoretical background on the notion of appraisal (to link individual differences to the influence of the task as a stressor).

5. INTERPERSONAL BEHAVIORS

This section presents our investigation of how participants interact with the two assessors during their presentation phase, with a particular interest in how individual differences modulate these reactions. While the task by itself suggests a unidirectional exchange (the participant is expressive and the judge listens passively), the nonverbal level of interaction is a space of constant mutualities and subtles influences. Following our conclusions from the literature review on bodily interpersonal processes, we investigate the multimodal synchrony occurring within the presentation phase of the interview. The aim is twofold: provide a better understanding about the role of interacting bodies in such a constrained setup and lay the ground for the modeling of a data-driven interactive judge.

5.1. Judges listening behaviors

In order to assess the interaction between the participant and judges, judges behaviors have to be extracted. Behaviors from the two judges were captured via a RGB camera. We extracted the quantity of motion (QoM) with the same method as applied to the participants. As the analysis is applied on the presentation phase, the judges are only listening to the participant without any verbal interventions. A first inspection at the judges videos revealed that the behavioral stream may better be characterized by a series of discrete behaviors than a continuous chain of movement. This pattern is typical of listening behaviors were discrete backchannel and posture shifts occur. Thus, we segmented automatically the QoM from the two judges to keep only these discrete behaviors following a four step procedure (Figure 48):

- Step 1 : 2nd order Butterworth low-pass filter at 0.5Hz to keep only gross variations
- Step 2 : from the filtered time-series, select segments above an arbitrary threshold of QoM (defined experimentally)
- Step 3 : from the filtered time-series, second selection of segment with accumulated QoM above an arbitrary threshold
- Step 4 : remove selected segment within the first and the last 3 seconds of the session (to be able to compute cross-lagged correlation)

The second step of our analysis was to remove "*irrelevant*" segments of behaviors. By "*irrelevant*" we means which are not related to the interaction while listening. The first source of irrelevance is when judges' movements are due to the disturbance of an external (of the interaction) source (e.g., phone ringing, disturbance by another experimenter or sneeze). The second source of irrelevance is the activity of writing: judges were sometimes taking notes during the

presentation which induced related behaviors (e.g., returning a paper sheet or changing of pen) not directly tied to the interaction. In sum, after the automatic segmentation, irrelevant segment were manually removed when caused by:

- Disturbance by an external source
- Writing related behaviors

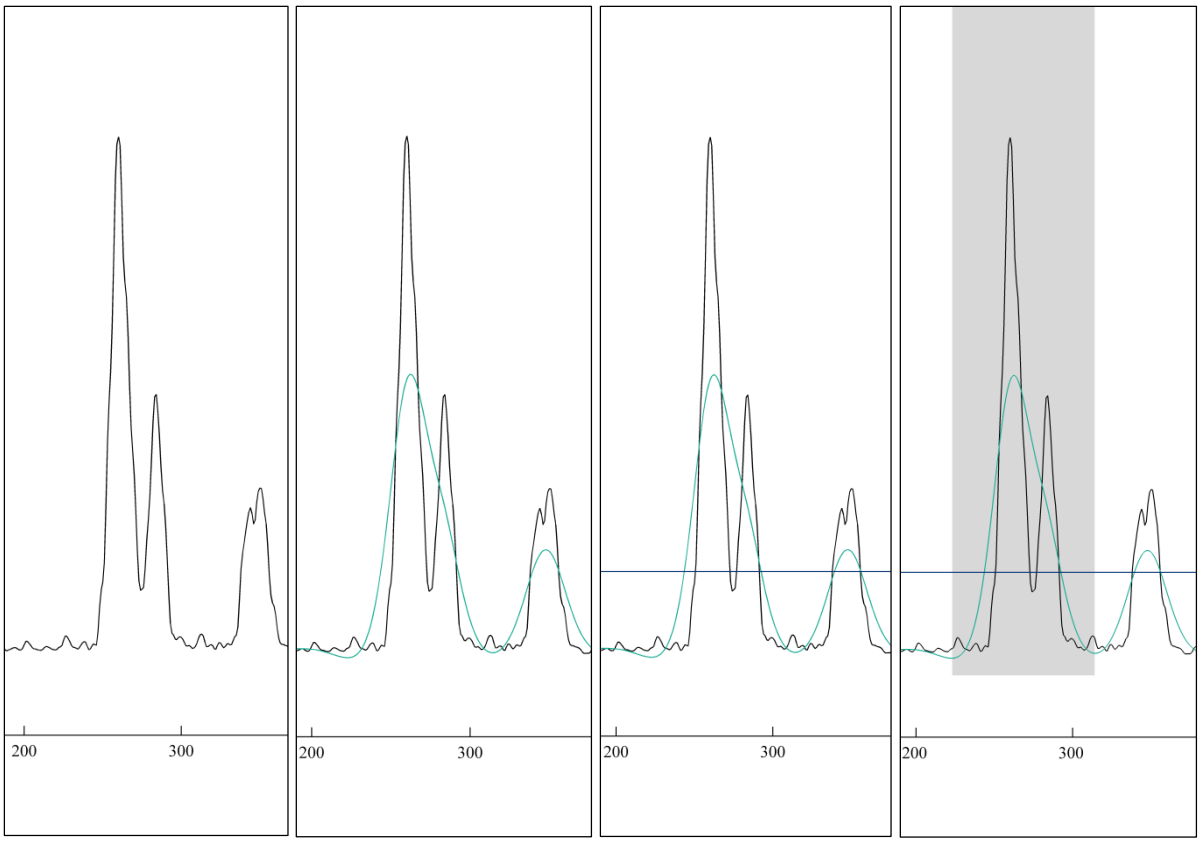

Figure 48: A) Quantity of motion from one judge, B) In red the filtered quantity of motion, C) Arbitrary threshold of QoM to select segment, D) selected segments based on the accumulated QoM in the selected segment.

Following this procedure, we extracted 260 segments (Table 27). Qualitatively, most of the segments include a shift in posture (which leads to greater amount of moving pixels in the image compare to hand or head movement alone). In the following of this chapter, most of the analyses will be conducted by taking into account only this segmented data.

Number of segments in the corpus	260
Averaged number of segment per session per judge	4.2
Mean length	140.8 frames
Standard deviation of lenght	54.4 frames
Maximum length	359 frames
Minimum length	72 frames

Table 27: extracted segment characteristics in COMP2

The reason for this is that there are few chances to have interpersonal influence or social coordination when the judges are not moving. When using this part of the corpus only, we will refer to COMP2-Segmented instead of COMP2.

Another methodological point to be defined is how to consider and analyze the behaviors of the two judges. Three approaches are possible:

- Analyzing their behaviors and interactions with the participant separately and then average the results

- Analyzing their behaviors as one unit, as if the participant was facing only one person. This choice would be motivated by the fact that the participant could perceive the judges' moves as a unified gestalt
- Analyzing their behaviors and interactions with the participant separately but also analyzing the interactions between the two judges. This choice considers the interaction as being triadic.

In this PhD thesis, we chose to analyze the data following the first approach: it makes fewer assumptions and is more straightforward for a first analysis of such a social interaction. Future researches could investigate the two other possibilities.

5.2. Associations between judges and participants behaviors

The first analysis we can run to evaluate the associations between judges and participants' behaviors is to compare participants' bodily behaviors variations between COMP2 and COMP2-Segmented. Overall, having a difference in one behavioral variable between the two corpuses would mean that participants had their behaviors modified while facing a judge move. As a remark, such an analysis gives no clue on the causality direction. For the purpose of this analysis, all behavioral variables are re-computed for both corpuses COMP2 and COMP2-Segmented. For COMP2-Segmented, bodily variables are computed for each segment in each presentation and then averaged for the entire presentation. Concerning MPF variables, we considered only frequencies above 1/Tmin Hz, where Tmin is the smallest length of our segments (Tmin = 72 frames, lowest frequency represented = 0.347 Hz). For COMP2, we cannot use bodily variables already computed in the previous section as such for comparison because of the large differences in sample length: macro variation included in the time scale of the presentation might not be visible in segments alone. Such a difference would be a confounding effect with the potential influence of judges' moves. To remove the possible confounding effect of data length, we re-computed the bodily variables from COMP2 with the same procedure as in COMP2-segmented but with segment randomly placed in the presentation. For example, if in one interaction COMP2-segmented is composed of 4 segments of 100 frames long each, we first compute the bodily variables for each segment and average them together (COMP2-segmented bodily variables) and secondly we randomly assign 4 segments of 100 frames long each to COMP2 and compute bodily variables for each segment and average them together (COMP2 bodily variables based on the same data length as COMP2-segmented).

Table 28 presents repeated measures ANCOVA for all behavioral variables where "*Factor*" represents the two conditions COMP2 and COMP2-Segmented (model 1). To investigate the role of individual differences, we computed four different repeated measures ANCOVA, each with a different individual difference as a covariate. Of particular interest (and reported in table 28) is the interaction effect between Factor and the individual difference. The main effect of Factor for each model is reported only once because it remains unchanged as we are in a repeated measure design with a constant (between subjects) covariate: "*e.g., Bill scores 70% for task 1 and 80% for task 2, but for each data point his age is the same. Ted scores 60% and 75%, but for each data point his age is the same. The mean performance of the whole group on task 1 versus task 2 should not depend on each participant's age; that is, it should not be based on a computation that involves the covariate of age, since the means for task 1 and task 2 are collapsed across age*" (Thomas 2009). A precaution to take to avoid that the main within effects are impacted by between subject covariates is to mean center the covariates (Delaney and Maxwell 1981).

	Factor		Factor * Extra		Factor * Agree		Factor * Neuro		Factor * Alex	
	F	p	F	p	F	p	F	p	F	p
Mutlivariate	4,469	,004	0,868	0,619	3,763	0,012	2,65	0,045	1,277	0,339
SD_COGx	,310	,110	0,646	0,428	0,015	0,905	0,053	0,819	0,066	0,799
SD_COGy	10,184	,133	1,891	0,180	1,189	0,284	0,747	0,394	0,072	0,790

SD_COP_COGx	4,031	,407	0,358	0,554	0,162	0,690	0,694	0,412	1,150	0,292
SD_COP_COGy	25,957	,961	1,323	0,260	1,249	0,273	1,257	0,271	0,399	0,533
MPF_COGx	177,734	,363	0,367	0,550	0,047	0,831	0,022	0,882	0,012	0,913
MPF_COGy	329,975	,274	0,089	0,768	0,225	0,639	0,906	0,349	1,481	0,233
MPF_COP_COGx	186,952	,150	0,089	0,767	0,758	0,391	0,181	0,674	1,166	0,289
MPF_COP_COGy	304,710	,176	0,176	0,678	3,023	0,093	2,347	0,136	0,789	0,382
MEAN_COPspeed	15,780	,101	0,041	0,841	0,008	0,930	0,094	0,761	0,592	0,448
Ellipse_COP	5,636	,301	1,005	0,324	0,533	0,471	0,135	0,716	0,287	0,596
MEAN_QoM	6,709	,019	2,952	0,096	1,612	0,214	1,751	0,196	0,150	0,701
SD_QoM	21,384	,095	2,646	0,115	2,020	0,166	2,743	0,108	0,532	0,471
MPF_QoM	114,648	,383	1,338	0,257	0,007	0,936	1,600	0,216	1,476	0,234
SD_IMP	15,392	,166	1,280	0,267	1,177	0,287	0,825	0,371	0,062	0,804
MPF_IMP	74,723	,003	0,910	0,348	0,841	0,367	1,509	0,229	0,005	0,943
MEAN_CI	,392	,092	0,108	0,745	0,258	0,615	2,575	0,119	3,149	0,086
SD_CI	37,766	,813	0,512	0,480	0,077	0,783	0,289	0,595	0,725	0,402
MPF_CI	76,667	,740	0,056	0,814	0,082	0,777	3,547	0,070	0,389	0,538

Table 28: Four repeated measures ANCOVA, each model with a different individual difference as a covariate.

The first important finding of this analysis is the significant association between judges' moves and participant bodily behaviors. This effect was significant at the multivariate level as well as for to variables: the mean quantity of motion (MEAN_QOM) and the mean power frequency of the first derivatives of motion quantity (MPF_IMP). Given the highly constrained setup and the subtle nature of judges' moves in job interviews, past researches never attempted to investigate the possibility of such a subtle mutual influence (Paxton and Dale 2013). In this study, following the belief that interpersonal interaction is pervasive, we showed that even under such impoverished setup participant and judges do interact nonverbally. The second interesting finding is that some of the selected individual differences were significant covariates of this influence. As expected, extraversion was not significant and agreeableness and neuroticism were significant at the multivariate level. Alexithymia appeared not significant contrary to our hypothesis. The multivariate level of analysis enable us to assess if any combination of our independent variables are significantly associated with the dependent variable but does not give further insight about which variable contributes alone to this effect. To look more closely at the effects, one possibility is to look in more details the univariate tests which approach significance.

A significant interaction effect at the univariate level indicates that the relation between the covariate (e.g., neuroticism) and the response variable (e.g., MEAN_QOM) differs between groups. Also known as testing for homogeneous within group regression slopes, an interaction is interpreted as a change in slope of the regression for the different groups. When an interaction appears significant, the interpretation of the effect is not straightforward. A possibility is to compute the differences for the response variable between the two groups (COMP2 and COMP2-Segmented), also called gain scores, and investigates the differences in correlations between covariates and COMP2 and covariates and gain scores. Table 29 presents the correlation between responses variables and covariates for all the univariate tests which approached significance.

	Factor * Extra		Var(All) * Extra		Var(Seg) * Extra	
	F	p	r	p	r	p
MEAN_QoM	2,952	0,096	0,072	0,699	-0,304	0,096
MPF_COP-COG_ML	3,023	0,093	0,040	0,831	-0,307	0,093
MPF_CI	3,547	0,070	0,113	0,545	-0,330	0,070
MEAN_CI	3,149	0,086	0,022	0,907	0,313	0,086

Table 29: Correlations between individual differences and bodily variables in COMP2 or in gain between COMP2 and COMP2-segmented.

The near significant interaction of extraversion (with factor) for the response of mean quantity of motion (MEAN_QOM) appears to be related to a negative correlation with this response: being more extroverted induces having a reduced influence of judges' moves on the quantity of motion. This effect is coherent with our result from the individual analysis: extroverts move less in the task and move less when judges move. Our hypothesis was that the reduced negative experience of more extroverted individuals would foster spontaneous synchronization and prevent from a freezing posture. Although no sign of freezing posture emerged, the activity of extrovert appeared relatively reduced. From these two consistent results, we propose a new conceptualization of the effect of extraversion in the job interview task: the reduced reactivity of more extrovert individuals might be due to a more detached approach to the situation. The rationale behind such a stance is that extraversion is associated with dominance, agency and independence, all these traits being associated with a more autonomous functioning, the task affecting less a more extrovert person. Following this line, extrovert individuals might have been calmer and less reactive than others. However, we are aware of the fact that such interpretation is tentative and need to be taken with caution.

The near significant interaction of agreeableness (with factor) for MPF_COP-COG_ML was related to a negative correlation: being more agreeable induces having a reduced postural stiffness when judges are moving (compared to when they are not). Alternatively put, agreeable individuals do not rigidify their posture when judges move. Although not expected, this result could be interpreted in two ways: as resulting from the association between agreeableness and the tendency to engage in smooth interactions or as resulting from an enhance emotion regulation which limits the postural freezing occurring under negative emotions. The correlation between neuroticism and MPF_CI show that neurotic individuals have less frequent variation of expansiveness (MPF_CI) when judges move. Lastly, the positive correlation between alexithymia and MEAN_CI show that more alexithymic individuals have more contracted movements (MEAN_CI) when judges move. These two last results are coherent with the hypothesis that these traits foster the tendency to freeze when threatens as discussed in the section on individual behaviors.

Overall, these results highlight the relevance of analyzing individual differences in such an interactive scenario (even supposed weakly interactive). Although precise hypotheses about their associations to specific bodily behaviors are still difficult, the current state of the art provides a good base to define working hypotheses. With this first analysis of the mutual influence between judges' moves and participant bodily behaviors, we found that extraversion, agreeableness, neuroticism and alexithymia tended to moderate this influence. Some tentative interpretations were provided: extraversion decreased the direct impact of judges' moves (less difference in overall quantity of motion) via an enhance distance from the threatening situation, neuroticism and alexithymia moderated freezing related variables (contraction index) which could be related to a decrease in the quality of the coordination, and agreeableness reduced postural stiffness, possible due to enhance smooth coordination or better emotion regulation.

In order to get more insight into these possible associations, we performed a complementary analysis by looking at interactional synchrony occurring within the presentation phase.

5.3. Synchrony analysis

In this section, we aim to investigate if judges and participants behaviors are synchronized in time. The hypothesis that interactional synchrony emerges in such a highly constrained task (judges are seated, listening in a very neutral attitude limiting the interaction) is a stronger hypothesis that of the precedent section (that judges' moves and participant behaviors mutually influence each other): in addition to be both disturbed, the behaviors should do so in a linearly

correlated manner (i.e., an increase in movement activity of the participant should be linearly related to an increase of movement activity of the judges). Such interactional synchrony has been investigated in affiliative tasks where participants wish to get along with others, and has been shown to be impaired with some negative elements are introduce in the interaction (e.g., an argument (Paxton and Dale 2013)). However, in the theoretical framework of this thesis, we advocate that even under minimalist non-affiliative social interactions some coordination patterns emerge. A property of interactional synchrony which play in favor of such a stance is that it does not require to match the same nonverbal modality: the timing of postural changes from the participant can be synchronized with an overall movement of a judge.

5.3.1. Methodology

To analyze such a synchrony, we performed a windowed cross-lagged correlation analysis (WCLCA) between the 8 time-series of participants' bodily behaviors and the QoM time-series from the two judges (each judges treated separately). We undertook such a linear approach to synchrony (instead of phase based synchrony analyses) as individuals' behaviors are not cyclical and stationary.

With these variables, 9 windowed cross-lagged correlations can be computed: one for each participant time-series of behaviors separately (with the judge's quantity of motion), and one taking the 8 variables together as a set to be correlated to the QoM time-series from each judge using canonical correlations. Canonical-correlation (CC) is a multivariate method which find the linear combinations of two sets of variables which have the maximum correlation with each other (Figure 49, (Sherry and Henson 2005)). As the level of analysis is the individual, we proceeded in order to keep the linear combination of the 8 participant's behaviors time-series for one participant consistent for the whole presentation: the optimized linear combination of variables is computed over the whole presentation and used as the projection basis for CCs applied on each window of the windowed cross-lagged correlation analysis. The method is understood as computing CC at the local level while using the projection at the global one as in (Ben-youssef, Shimodaira, and Braude 2013). Consequently, each participant will be correlated to judges' moves via CC on a different projection plane, allowing for individual differences in the preferred channel to synchronize. The projection is done on the sample data of interest: on the entire presentation (in COMP2) when interested in interaction synchrony over the whole sequence and on the segmented presentation (in COMP2-Segmented) when interested in interaction synchrony over the segmented sequence.

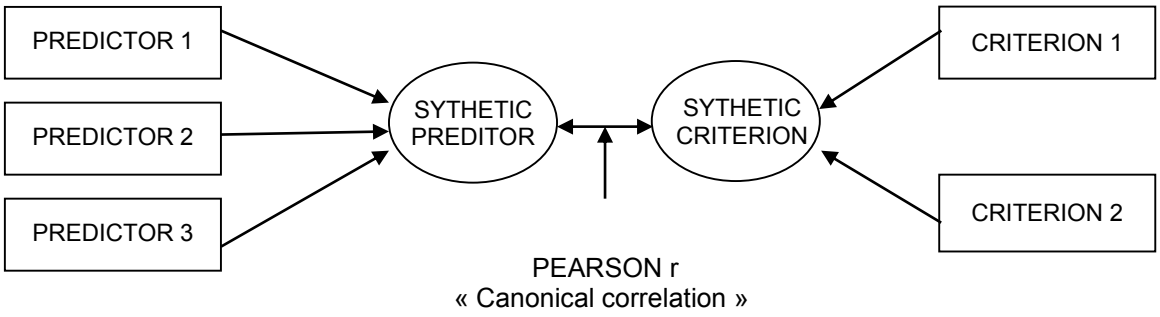

Figure 49: schematic representation of a canonical correlation analysis from (Sherry and Henson 2005).

Computing both WCLCA for participants' bodily variables separately and as an optimal combination via canonical correlation will enable us to study different aspects of the synchrony pattern: the overall synchrony emerging from the concurrent interplay of the different behavioral modality (magnitude and lag), the specific contributions of each modality to the synchrony by examining the projection vector of the CC, and the separate synchrony emerging on each behavioral modality. The two last aspects might be very similar though.

When computing WCLCA, an important parameter to define is the time window of the cross correlation: how many data points are including in the local correlation computation at each frame. The current literature about synchrony is inconsistent about this choice. (Richardson, Dale, and Kirkham 2007) suggest the use of a 3 seconds time window on a conversational task which enables to capture the typical periods in which both conversants were acting as speakers and listeners, advice followed by (Paxton and Dale 2013). However, two other recent studies about conversations chose radically different time windows: (Tschacher, Rees, and Ramseyer 2014) chose a large time window of 30 seconds "*to account for the relatively more dynamic and shorter turn-taking latencies in argumentative interaction compared to a psychotherapy setting*" and (Latif et al. 2014) went for a shorter window of 0.5 s "*selected based on evidence regarding the timing and duration of "conversational events" indicating that individuals engaged in conversations are able to predict movements and speech of those they are speaking within 500 ms*". (Boker et al. 2002) proposed a sound description about what rationale could guide the choice of the time window: depending on the objective of the study, it should be a tradeoff between reliability (bigger time window is better) and sensitivity (smaller time window is better). Thus if researchers are interested in overall synchrony within the interaction, there is no need to shorten the time window: a large time window such as 30s is more reliable. However, if one is also interested in the dynamic variations in synchrony, the sensitivity of the cross-correlation become important: a too large time window would erase those subtle variations. In our case, we are interested in having a good sensitivity to analyze the subtle mutual adjustments within the interaction. To choose the time window of the WCLCA, we run 7 different WLCA with different time window (seconds: 0.5, 1, 2, 3, 4, 5, 6s) at 9 different time lags (seconds: -3, -2, -1, -0.5, 0, 0.5, 1, 2, 3) with both the projection of the CC done on COMP2 and COMP2-segmented. From this analysis we can look at two results: first is there any synchrony pattern emerging with the largest time window? A synchrony pattern is characterized by an increasing of synchrony at a specific lag following a bell shape: the larger the lag outside this bell shape, the less likely the synchrony. If yes, then interactional synchrony emerged during the interaction which justifies the following of the analysis. Secondly, we can look at which is the smallest time window which conserve this pattern to increase the sensitivity of the analysis. Figure 50 presents the result of this analysis.

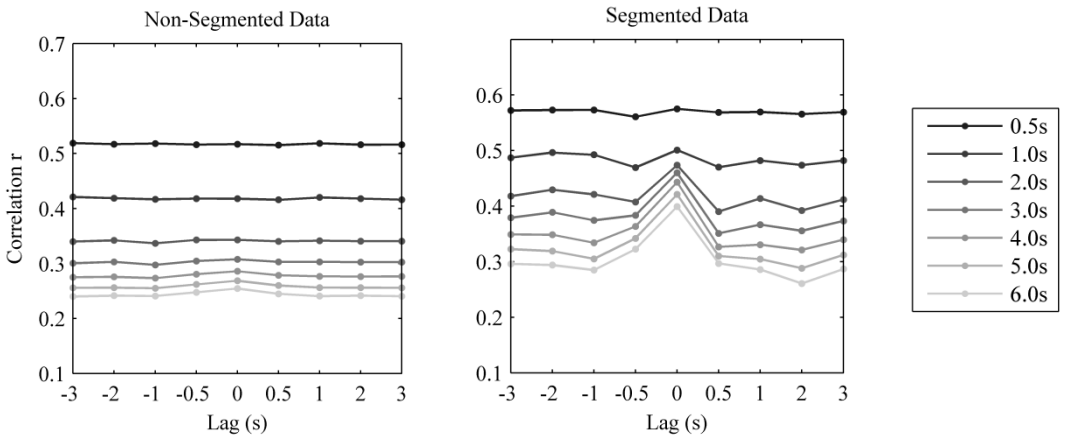

Figure 50: WCLCA on COMP2 and COMP2-segmented with different time windows

Results from these first WCLCA are encouraging: a synchrony pattern is present at the 6 seconds time window only for the segmented data. It both confirms the presence of interactional synchrony in our setup and validates the usefulness of the segmentation procedure we undertook. In terms of sensitivity, the time-windows of 0.5s and 1s are clearly too small leading to random results of cross-correlation (no influence of lag). The more sensitive choice would be a 2s lag window, but in our case we chose a 3s time window to keep a certain level of reliability.

The last methodological aspect concerns the ground truth definition. Various methods exist to distinguish genuine synchrony from random pseudo-synchrony (Ramseyer and Tschacher 2010). In our analysis, we computed WCLCA

for pseudo-pairs of participant-judge using a shuffling procedure: the WCLCA is conducted a second time for each participant with a judge chosen randomly from all other pairs. As presentation phases vary in time, time-series are aligned at the beginning of the presentation and the longest time-series is truncated to fit the length of the shortest. The procedure is the same as for the real pairs: projection at the global level on both the entire presentation and the segmented presentation.

We therefore have a 2*2 groups of WCLCA (real pairs / pseudo pairs * segmented / non segmented corpus). WCLCA are computed with a 3 second time window over a ±3s lag (at 25 fps). Figure 51 shows an extract of a correlation map with identified segment indicated.

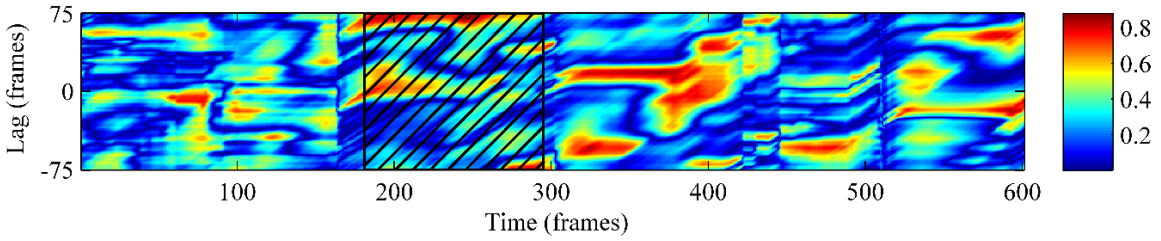

Figure 51: Example of one extract of a correlation map analysis resulting from the WCLCA with the 8 variables combined. A hatched zone highlights the location of an identified segment of judge movement.

5.3.2. Results: General synchrony

To firmly establish the possible presence of synchrony in our corpus, we present in Figure 52 the correlation coefficients for the WCLCA with the 8 time-series combined via CC averaged over all pairs with standard deviation across lags for the four groups. Across lags, the correlation coefficients for the real pairs in the segmented corpus were all significantly higher than the correlation coefficients for the pseudo pairs in the segmented corpus apart from 5 lags (lags 16, 17, 18, 19, 20 and 21). Interestingly, in the non-segmented analysis, correlation coefficients for the real pairs were not significantly different from the pseudo pairs confirming the relevance of our segmentation procedure. The peak correlation for the real pairs in the segmented corpus was r=0.4675 at lag=0 (compared with the pseudo pairs correlation coefficient: $t(60)=6.877$, $p=0.000$).

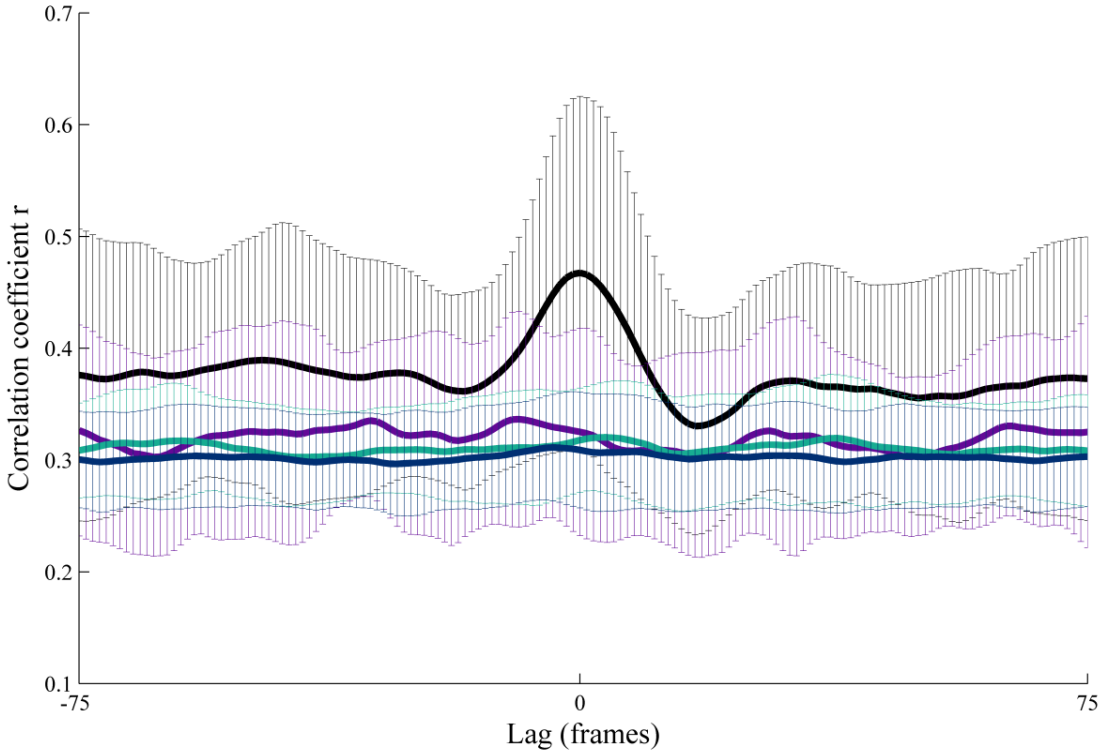

Figure 52: Correlation coefficients (for the WCLCA with the 8 time-series combined) averaged over all pairs (n = 31) with standard deviations across lags. BLACK: real pairs segmented; PURPLE: pseudo pairs segmented; GREEN: real pairs non-segmented; BLUE: pseudo pairs non-segmented.

To further investigate the separate role of each nonverbal modality, we compared the correlation coefficient between real and pseudo pairs for the segmented corpus from the WCLCA run individually on each modality (Figure 53). Only body motion impulsivity (IMP) of real pairs was not significantly different from pseudo-pairs correlations. Among the others, displacement of the gravity center in the anterior-posterior (COG_AP) and the media-lateral plane (COG_ML) were the most strongly synchronized signals.

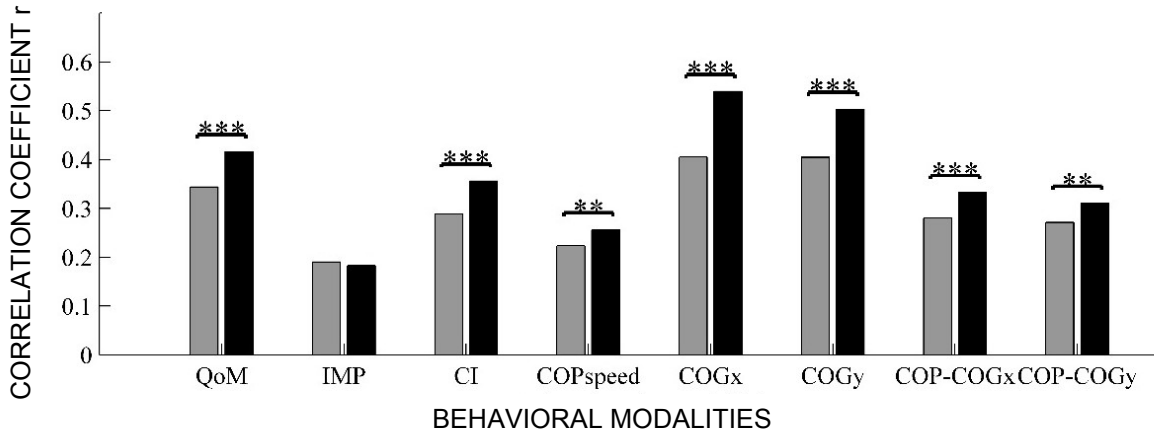

Figure 53: Correlation coefficients for the 8 WCLCA separately averaged over all pairs (n = 31) at lag 0. The red bars are for pseudo pairs segmented and the black bars are for real pairs segmented.

A complementary view is to look at the projection of the 8 times series in the canonical correlation across participants. Figure 54 presents the correlation coefficients between the 8 original variables entered in the combined WCLCA with the canonical variable (synthetic predictor). These loadings account for the amount of variance (if squared) which contributes to the predictor for each of the 8 variables. Overall, the pattern of contributions is similar to Figure X with COG_AP and COG_ML as the main contributors. The total explained variance of the 8 variables is 13,41%. The

standard deviations presented in Figure 54 show high variability in this pattern which could be investigated in future works.

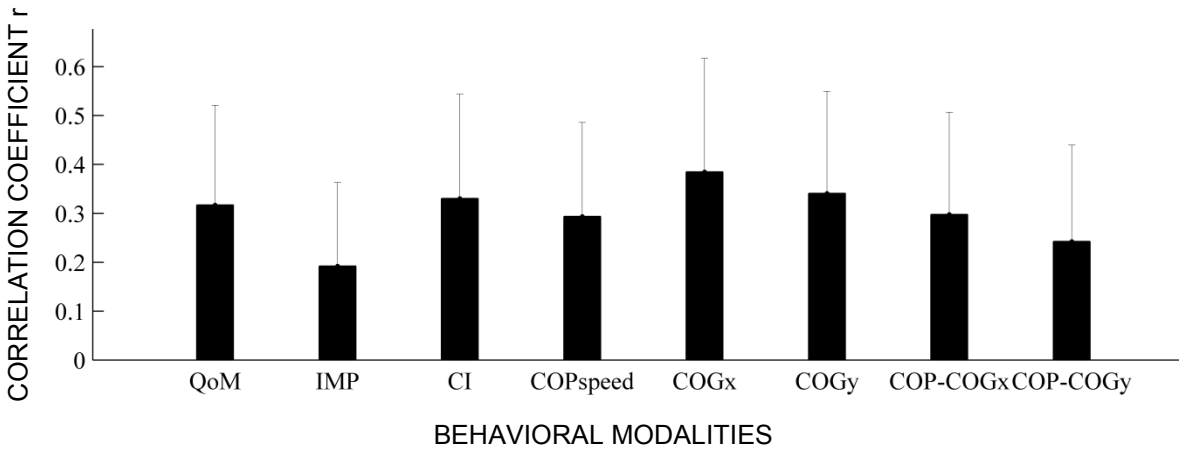

Figure 54: Correlation coefficients between the 8 original variables entered in the combined WCLCA with the canonical variable (synthetic predictor) averaged over all pairs (n = 31) with standard deviations at lag 0.

Together, these results about the presence of interactional synchrony in the presentation of our job interview protocol provide a solid ground for the more systematic investigation of synchrony in social interaction. Although most of the study on interactional synchrony focus on affiliative setup, some recent works evidenced that interpersonal coordination can arise in less affiliative tasks (Paxton and Dale 2013)(Tschacher, Rees, and Ramseyer 2014). Our results extend these studies to a more extremely stressful context where negative emotions are pervasive. We showed how a careful data analysis and segmentation as well as a more rational choice of time window are essential for the study of such subtle phenomena.

Additionally, the use of canonical correlations provides a more flexible approach to interpersonal synchrony allowing for various linear combinations across behavioral channels. In our study, we found that the respective contribution of each bodily variable to the overall canonical correlation was consistent with their separate associations with judges' moves. The canonical correlation also highlighted a large variability in these relative contributions which means that participants differ in the way to synchronize with judges (e.g., some participants synchronized more their global motion activity and other are more coordinated via their postural sway). As such, this finding confirms the hypothesis that the process of interpersonal synchrony is a-modal and highly flexible. Not studied in this PhD thesis, these individual differences are a promising route to explore in future research about interactional styles.

5.3.3. Results: individual differences

The second step of this analysis is to investigate how individual differences modulate this synchronization pattern. Figure 55 presents correlation coefficients (for the WCLCA with the 8 time-series combined via CC) across lags but not averaged over the 31 pairs (the 31 curves are plotted). This figure reveals how varied the patterns are, in range and lag patterns. In our analysis, a bigger lag means that the participant is synchronized with a bigger lag (the participant is late). Two elements are of particularly interest in our study on individual difference in synchronization: the intensity of the synchronization and the lag of the synchronization. For each pairs, we extracted the maximum correlation nearest to lag 0. The corresponding correlation coefficient and lag are then correlated with our individual differences set.

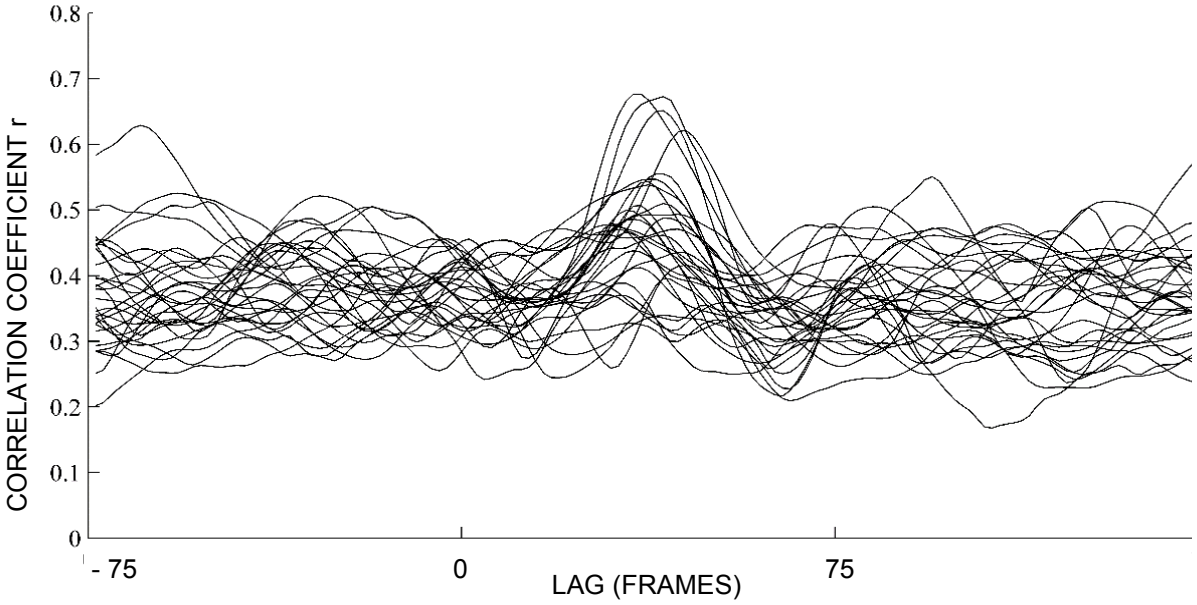

Figure 55: correlation coefficients (for the WCLCA with the 8 time-series combined) across lags but not averaged over the pairs (n = 31).

Table 30 presents the correlations between maximum and lag of maximum correlation (near lag 0) for the 9 WCLCA (the 8 bodily variables separately and the CC) with our set of individual differences.

			Extra	Agree	Neuro	Alex
Max	QoM	r	,116	,138	,073	,226
		p	,549	,476	,706	,238
	IMP	r	,292	,212	,048	-,080
		p	,124	,269	,805	,680
	CI	r	-,063	,004	-,087	,120
		p	,747	,983	,654	,534
	COPspeed	r	-,148	,192	,048	,221
		p	,444	,318	,803	,249
	COG_AP	r	-,121	-,145	,345	,157
		p	,530	,452	,067	,415
	COG_ML	r	-,129	,092	-,034	,057
		p	,506	,634	,860	,767
	COP-COG_AP	r	,089	,140	-,127	-,067
		p	,646	,468	,513	,730
	COP-COG_ML	r	-,011	,279	-,070	-,192
		p	,954	,142	,720	,319
	ALL	r	,028	,056	-,365	-,098
		p	,885	,775	,052	,612

			Extra	Agree	Neuro	Alex
Lag	QoM	r	,270	,040	-,171	,003
		p	,156	,837	,374	,986
	IMP	r	,148	,109	-,036	,134
		p	,444	,572	,854	,488
	CI	r	,137	,164	-,047	-,043
		p	,478	,394	,809	,826
	COPspeed	r	,203	,023	-,085	,180
		p	,290	,906	,663	,351
	COG_AP	r	-,139	,064	-,138	,312
		p	,471	,740	,477	,099
	COG_MP	r	,030	-,082	,032	,130
		p	,879	,673	,871	,500
	COP-COG_AP	r	-,162	,243	,089	,356
		p	,402	,204	,647	,058
	COP-COG_ML	r	-,097	-,239	-,101	,375
		p	,616	,212	,602	,045
	ALL	r	,329	,162	-,161	,074
		p	,081	,400	,404	,704

Table 30: Correlations between individual differences and synchrony max correlation and lag of max correlation.

The only strictly significant correlation appeared between the lag of the participant regarding the synchronization of COP-COG_ML (postural stiffness in the medio-lateral plane) with judges' moves and affective alexithymia. This pattern is difficult to interpret as the COP-COG_ML signal is supposed to represent micro-movements (stiffness) less subject to direct linear coupling with external signals. However, the fact that two other lags of postural variables (COG_AP and COP-COG_AP) are correlated in the same direction to affective alexithymia indicates a consistent pattern. It seems that more alexithymic individuals have lagged postural coordination. This result contradict our first interpretation (chapter 2 and 3) that more alexithymic individuals have an impaired ability to delay too reactive behaviors to perform more adapted reactions leading to coordination of better quality (smoother). The highly

emotional nature of the task might confuse the possible source of effects on the coordination pattern. We could interpret this pattern in purely emotion regulation terms: being more aroused, more alexithymic individuals relied less on heuristic with a thigh motor control (more postural stiffness) inducing a lag in their reactivity. Perhaps such lagged coordination might be an indication of impaired quality of coordination as hypothesized. Still, the clear nature of this pattern requires more investigation. Also, no evidences were found of reduced synchrony due to the indirect effect negative emotions.

Approaching significance, neuroticism was associated with reduced overall bodily synchrony but increased postural synchrony in the AP plane. The overall reduced synchrony appears in line with the idea that neuroticism induces more negative feelings because of an increased perceived ego-threat. Experiencing more negative emotions impairs the possibility of spontaneous coordination with other systems. However the enhance synchronization in the AP plane is less clear. Finally, extraversion tended to be positively correlated with overall lag. This result appears consistent with our last conceptualization of extravert as more detached from the judges' judgments and task context. As expected here, agreeableness was not related to any synchronization variables.

5.3.4. Segment exploration

The previous synchrony analysis is limited in that synchronization is analyzed at the averaged level for each participant. As such, it provides no information about the temporal development of synchrony for one particular segment (e.g., strong synchrony at the beginning of the segment decreasing over time). The specific pattern of our task (public speaking with listening judges) and the segmentation we proposed enable to examine synchrony with a different approach. In this section we propose an exploratory approach to characterize each segment separately with different features summarizing the synchrony pattern.

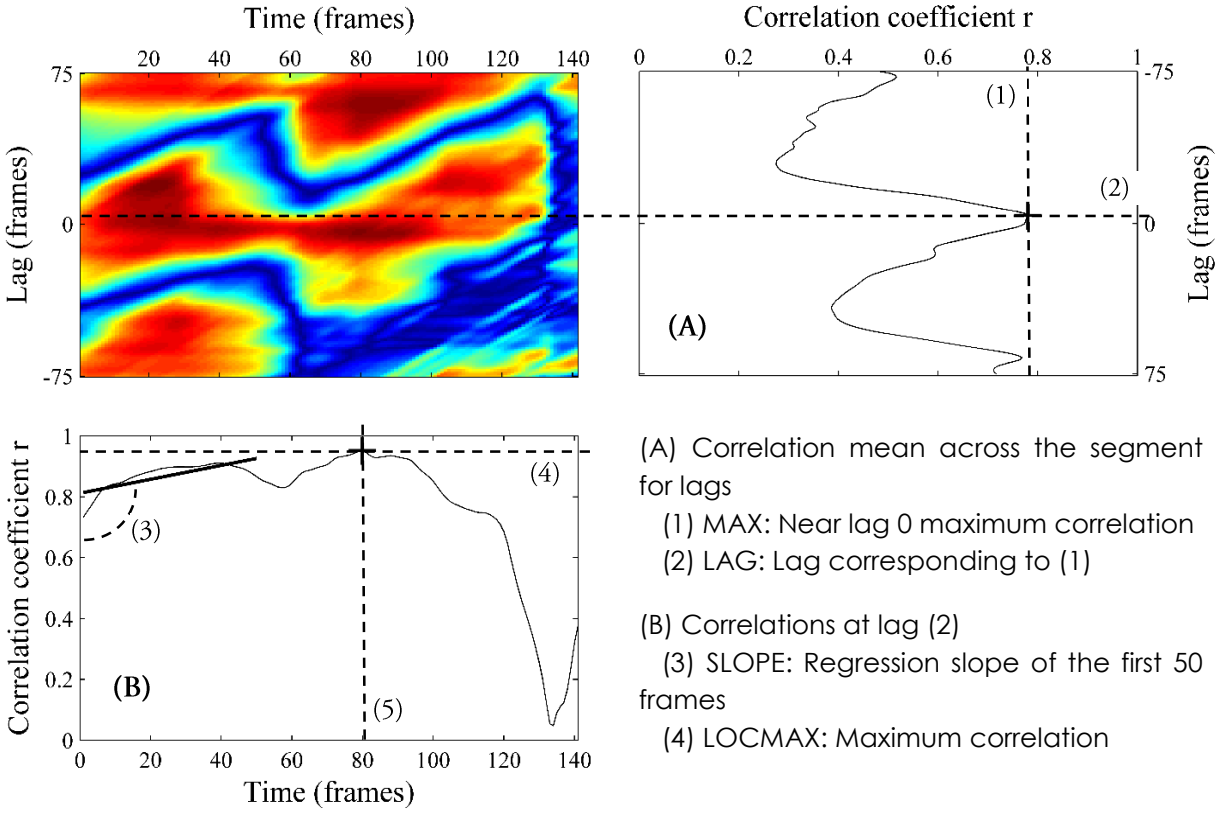

Figure 56: Example of one segment correlation map with the five extracted features.

The analysis of the lag in the previous section was already relatively novel in the study of interactional synchronization. The segmental analysis presented here is therefore a pilot study without further hypotheses. Figure 56 shows an example of a correlation-map for one segment and schematizes the extraction of 5 variables. These five variables are computed for the 9 time-series, for the 260 segments.

		1	2	3	4	5	6	7	8	9
LOC_LAG	IMP_LOCLAG	,726	,017	,021	,151	,011	,004	-,034	-,050	-,175
	QoM_LOCLAG	,697	-,043	,042	,137	,073	,049	,002	-,064	-,248
	COPCOG_AP_LOCLAG	,673	,136	-,031	,016	-,033	,004	-,047	,091	,013
	COPCOG_ML _LOCLAG	,603	-,026	-,165	,039	-,018	,143	,153	-,007	-,050
	ALL_LOCLAG	,572	-,079	,150	-,106	-,028	-,111	,053	-,069	,017
	COG_ML_LOCLAG	,547	,034	-,085	-,003	,067	-,058	-,123	,233	,116
	COPspeed_LOCLAG	,537	,031	-,135	,040	-,072	-,081	,074	,057	,074
	CI_LOCLAG	,513	-,082	,194	-,077	-,019	-,105	-,040	-,022	,267
	COG_AP _LOCLAG	,510	,007	,071	-,054	-,105	-,046	-,007	,026	-,125
	COG_AP _LAG	,199	,127	,081	-,041	,082	-,132	,086	-,170	-,115
QoM_MAX	IMP_MAX	-,056	,856	-,002	-,088	,027	-,010	-,142	-,032	,051
	IMP_LOCMAX	,179	,807	,077	-,177	,007	-,068	-,118	,100	,111
	QoM_LOCMAX	,085	,744	-,054	-,009	-,109	,118	,201	,028	-,058
	QoM_MAX	-,183	,705	,024	,095	-,092	,156	,115	-,054	,002
COG_MAX	COG_ML _LOCMAX	,156	,026	,746	-,022	,213	-,004	,011	-,289	-,124
	COG_ML _MAX	-,230	,019	,669	-,026	,222	-,068	-,037	-,102	-,098
	COG_AP _MAX	-,269	-,003	,638	,150	-,164	-,032	,003	,105	-,024
	COG_AP _LOCMAX	,115	,034	,629	,043	-,203	-,079	-,077	,229	,063
	COPspeed_LAG	,010	-,152	,355	-,168	,127	,107	,049	-,348	,067
	COPCOG_ML _LAG	,057	-,061	,354	-,011	-,231	,049	,095	-,133	-,305
SLOPE	ALL_SLOPE	-,039	-,151	-,017	,637	-,045	,076	-,052	,040	,162
	COG_AP _SLOPE	,073	-,026	,211	,576	-,237	-,008	,078	,054	,078
	COPCOG_ML _SLOPE	,014	-,127	-,206	,544	,140	,033	-,016	,047	-,224
	COPCOG_AP _SLOPE	-,129	-,064	,017	,523	-,058	-,139	,015	,282	-,063
	IMP_SLOPE	,033	,209	,086	,508	,036	-,095	-,143	-,275	-,127
	QoM_SLOPE	,157	,152	,028	,502	,176	,118	-,154	-,194	,216
	COG_ML _SLOPE	,148	-,113	,012	,357	-,048	,096	-,118	,268	,095
COPCOG_ML _MAX	COPCOG_ML _MAX	-,199	-,038	,046	-,023	,873	-,023	,017	-,034	,093
	COPCOG_ML_LOCMAX	,167	-,070	,057	-,077	,829	-,072	,066	,033	,066
	CI_LAG	-,172	-,002	-,149	,192	,302	-,255	,070	-,117	,104
CI_MAX	CI_LOCMAX	,035	,058	-,082	,000	-,079	,836	,076	-,069	-,031
	CI_MAX	-,205	,055	-,058	,059	-,087	,791	,037	-,062	-,009
	ALL_LOCMAX	,146	,015	,238	,000	,159	,468	,023	,335	,041
	ALL_MAX	-,161	,041	,281	,025	,136	,402	-,004	,342	,042
COPspeed_MAX	COPspeed_MAX	-,081	,027	-,055	-,094	,032	,062	,882	-,081	,021
	COPspeed_LOCMAX	,138	-,021	-,026	-,085	,106	,103	,849	,053	,048
	ALL_LAG	,033	-,038	,155	,096	-,191	-,241	,359	-,125	,195
COPCOG_AP _MAX	COPCOG_AP_LOCMAX	,197	,078	-,002	,144	,191	-,099	,236	,647	-,085
	COPCOG_AP _MAX	-,184	,102	,093	,121	,161	-,206	,141	,628	-,121
	IMP_LAG	-,039	,052	,119	,065	,138	-,080	,161	-,477	,061
CI_SLOPE	CI_SLOPE	,028	-,027	-,028	,256	,115	,101	-,016	-,144	,659
	QoM_LAG	-,151	,159	-,026	-,082	,086	-,130	,032	-,086	,552
	COG_ML _LAG	,045	,047	,226	,091	-,009	,023	-,029	-,133	-,398
	COPCOG_AP _LAG	-,027	-,071	,080	,096	,016	,093	,141	-,276	,376
	COPspeed_SLOPE	,030	,098	-,098	,149	-,112	-,084	,207	-,226	,282

Table 31: Components loadings for the 9 components models.

In addition to the computation for each segment of the maximum correlation when average across lags (MAX) and the corresponding lag (LAG), we extract three variables from the correlation data if the segment at LAG: the maximum correlation (LOCMAX), the corresponding lag (LOCLAG) and the regression slope of the first 50 frames of the segment (SLOPE). Although MAX and LOCMAX might be very close, LOCLAG provides information about how

late in the segment the participant and the judge are most synchronized and SLOPE give some information about how fast the participant and the judge reach their highest level of synchronization. This extraction procedure provides us with 45 variables. Before averaging them for each participant, we run a PCA on the 260 segments to reduce the dimensionality. The scree plot suggested that the 6 (variance explained: 37,1%), 9 (variance explained: 47,6%) and 11 factors solutions (variance explained: 53,6%) best fit the model. Inspection of the tree solutions revealed the 9 component solution was best interpretable (Table 31).

The first component groups the LOCLAG of all variables and is therefore associated with the lag of the synchronization within the segment cross-modally. Similarly, the component 4 regroups all the variables related to the SLOPE. The component 2 groups the MAX and LOCMAX from motion quantity and its first derivatives (IMP): it is assimilated with the synchrony quantity of the general bodily activity. Component 3, 5, 6, 7 and 8 show similar patterns for COG, COPCOG_ML, CI, COPspeed and COPCOG_AP respectively. The last component is less coherent with more variables weakly correlated. Factor scores for the 9 components are computed using the regression method and averaged for each participant. Then, associations with individual differences are analyzed via Pearson correlations (Table 32).

		Extra	Agree	Neuro	Alex
P1_LOC_LAG	r	,170	,132	-,096	-,072
	p	,379	,494	,619	,710
P2_QoM_MAX	r	,154	,086	,284	,203
	p	,424	,657	,135	,291
P3_COG_MAX	r	,133	,207	,055	-,057
	p	,491	,281	,776	,768
P4_SLOPE	r	-,296	-,003	-,202	-,064
	p	,119	,989	,294	,740
P5_COPCOGy_MAX	r	,029	,316	-,222	-,221
	p	,880	,095	,248	,248
P6_CI_MAX	r	,033	,002	-,098	,003
	p	,864	,991	,612	,990
P7_COPspeed_MAX	r	,039	,273	-,071	,145
	p	,841	,152	,714	,453
P8_COPCOGx_MAX	r	-,010	-,259	,043	,079
	p	,958	,175	,823	,685
P9_CI_SLOPE_QoM_LAG	r	-,176	-,121	-,004	,014
	p	,360	,531	,985	,943

Table 32: Correlations between individual differences and components from the segmental synchrony analysis.

No significant correlations appeared revealing no further insight with such an approach. Perhaps the main limitation such an approach is that the level of the segment is very noisy, each segment being really different in terms of length and pattern. Future research could dig in this direction by proposing a larger number of segment descriptors which are less prone to random noise and more consistent across participants.

5.4. Discussion

In this section, we undertook the analysis of the job interview as a social interaction. To investigate the mutual nonverbal adjustments between the participant and the judges, we first examined the listening bodily behaviors of the two judges. Mostly not moving, the judges made few subtle moves in a discrete manner within each session. Thus, we segmented the corpus accordingly in order to focus on judges' movement phases.

The social interaction was studied with two different approaches: by comparing the participants' bodily signature within phases where judges moves with phases were the judges do not moves; and by computing the synchrony level via cross-correlation at a multimodal level via canonical correlation. Although the situation is highly constrained and stressful, both analyses revealed the presence of mutual adjustments: participants' bodily behaviors changed when judges moved, and synchrony occurred in a multimodal way. Additionally, the synchrony peak was at lag 0. Even if individual differences exist in terms of lag, it remains near perfect timing (lag 0) revealing a subtle coupling (more than just the reaction of one member to the behavior of another). The presence of bodily interpersonal processes in such a drastically codified task advocates for a more systematic study of interpersonal coordination and opens an interesting

line of research for the special case of job interviews. Additionally, the canonical correlation revealed that individuals do not synchronize with the judges in a unified way: high variability emerged in the preferred nonverbal synchronized channel. This result confirms the view that synchrony is not restricted to matching modalities: entrainments can occur across various modalities. The precise theoretical implication of such result need further study to determine which modalities can be subject to synchrony or not. Perhaps the fundamental requirement of a modality to be synchronized is to be a motion related modality: for example body movements and prosodic features are known to be "*synchronizable*". The future study of these "*interactional style*" is a promising route toward the better understanding of the multimodal tuning in social interactions.

In terms of the individual differences influences on interpersonal phenomena, our hypotheses were based both on the original hypotheses made in chapter 2 and 3, but also on refinements in order to take into account the specificity of the task: participants are being judged for a job. This aspect induced an ego-threat which can lead to high negative emotions, themselves associated with impaired spontaneous coordinations. Table 33 summarizes all the near significant (<0.1) effects we found in the individual and interpersonal analyses. Agreeableness was the trait the least associated with any bodily variables, either at the individual or the interpersonal level, as expected given the type of the presentation task: totally non-affiliative. Alexithymia and neuroticism were both associated with postural freezing at the individual level, which was confirmed at the judges' influence level. The greater discrimination between alexithymia and neuroticism appeared in the synchrony analysis: alexithymia was associated with postural lag related variables (greater alexithymia associated with greater lag) and neuroticism with the amount of overall synchrony (greater neuroticism associated with lower synchrony). In the case of alexithymia, we interpret it as an indirect effect of bad emotion regulation: experiencing more negative emotions, more alexithymic individuals relied less on spontaneous rapid reactive behaviors. Although this could be associated with lower quality coordination, our original interpretation that low alexithymia enables the delay of too reactive behaviors to perform more adapted reactions seems to not work here. One possible reason is that the effect of emotions overwrote the more general effect of emotion regulation. The fact that neuroticism was associated with impaired overall synchrony was coherent with our emotional hypothesis: experiencing more negative emotions impairs the synchronization phenomena. The precise reason why alexithymia and neuroticism have different effect on the coordination is unclear. Perhaps one promising line of research would be to distinguish more precisely the emotional experience associated to such a task. Extraversion was initially interpreted via the association of the trait to emotional positivity. However, the consistent association of the trait with less movement activity as well as less stiff posture encouraged us to reformulate our interpretation as a detachment from the situation. Similarly to the potential effect of dominance or independence, more extrovert individuals were less directly affected by the task.

Although we attempted to extract interpretable bodily variables and build sound hypotheses from our literature review, we found difficult to interpret our results in the details. Some associations are difficult to explain (why neuroticism is associated with more synchronization of the COG_AP?) and the more general patterns are not so clear. One possibility is that approach-avoidance (AP plane) mechanisms are differently synchronized. Yet, the results stay unclear, which can be partially due to the current limits in the state of the art (the understanding of the complex human motor control system or the precise evaluation of individual differences), as well as to the complexity of the task which involve multiple phenomena co-occurring (personalities, bodies, emotions, cognitive appraisals, etc.). In addition, as the canonical correlation highlighted, individuals vary in the preferred way to synchronize which might reduce the effect of one individual difference on one particular behavioral variable. Lastly, the fact that the overall synchronization is subtle might not help to identify robust and recurrent patterns of influences. Combining all those difficulties is probably the cost to access to more spontaneous and ecological studies.

	Alexithymia		Neuroticism		Extraversion		Agreeableness	
Individual	MPF_COG_ML	-0,406	MPF_COG_ML	-0,489	SD_COG_AP	-0,385	SD_COP_COG_AP	0,329
	MPF_COP_COG_ML	0,464	MEAN_QoM	-0,61	SD_COG_ML	-0,362		
	MEAN_QoM	-0,428	SD_IMP	-0,363	MPF_COP_COG_ML	-0,349		
					Ellispe_COP	-0,441		
Judges' influence	MEAN_CI (seg)-(all)	0,313	MPF_CI (seg)-(all)	-0,33	MEAN_QoM (seg)-(all)	-0,304	MPF_COP_COG_ML (seg)-(all)	-0,307
Judges' synchrony	Lag_COG_AP	0,312	Max_COG_AP	0,345	Lag_ALL	0,329		
	Lag_COP_COG_AP	0,356	Max_ALL	-0,365				
	Lag_COP_COG_ML	0,375						

Table 33: Summary of highest associations between individual differences and behavioral variables

A point which could be addressed in future research is how the bodily fluctuations at the individual level influence the social interaction: does a more stiff posture influence the synchronization pattern? Given the fact that the stability level differs from one subject to another (Isableu et al. 2011), it might be not surprising that the interaction style is impacted.

Lastly, in our corpus the judges' behaviors are grossly captured by one video camera. The use of better resolution and 3 dimensional cameras (depth cameras) would bring additional dynamic information such as the direction of the postural moves or the specific head movements. The analysis of gaze patterns and mutual gazes is without doubt a determining aspect of the job interview task. Additionally, the limited amount of information in the judges' videos led us to segment our data given the apparent inactivity of judges during some period. The use of pressure map on judges' seats and eye tracking would probably reveal a more continuous pattern of interaction.

As a general conclusion of the analysis of the job interview corpus, we can say that participants and judges do coordinate together, that they do so in a differentiated way as a function of the identified individual differences, and that the nature of the task – here a job interview – is essential to consider in order to interpret these interaction patterns.

6. TOWARD A VIRTUAL JUDGE

The study of the job interview corpus revealed the encouraging results that interviewee and interviewers do interact with their bodies in a very subtle way. The last step of our work is to lay the ground for the development of a virtual judge which could reproduce these subtle patterns.

6.1. Goal of the virtual judge

The development and study of virtual judges in the HCI community is gaining increasing interest. While most of the available works propose sophisticated interaction models including a cognitive model enabling to infer states and intentions of the participants (Anderson et al. 2013), we found no proposal for a low level / reactive module of the interviewer. As highlighted in the state of the art (chapter 3) and the introduction of this chapter, this might be due to a lack of attention to the importance of more direct interaction phenomena such as bodily interpersonal processes. In this section, we focus on this very specific part of the interviewer: its reactive listening behaviors. We argue that such a low level social tuning provide the ground for a deep social presence feeling (Biocca, Harms, and Burgoon 2003), a necessary step toward a more engaging application.

The development of this virtual judge is done with two goals in mind:

- The future development of an application which could help individuals train to face their emotions while engaged in a job interview. In such application driven goal, the believability of the virtual character behaviors is essential and perhaps the most basic behavior is the activity of listening.
- The future development of an experimental tool which could help scientists to investigate how individuals react in job interview setups in a much more easy and controlled way. Some virtual audiences exist but to date no truly interactive interviewer based on real word data has been proposed. It is only at this condition (reproducing a real word interactive pattern in a data driven approach) that the application can serve an experimental purpose.

In this section, we present the functional design such an application as a proof of concept to be developed (after this PhD thesis). In order to stick to our data analysis, we focus on the interviewers body movements without considering facial expressions, gaze and writings. All three could be analyzed and implemented in future steps following the same approach as in this thesis.

6.2. Virtual judge design

6.2.1. Nonverbal behaviors: postural moves

As in most job interview situations, the judges in our corpus were seated in front of the participant. As the analysis is applied on the presentation phase, the judges are only listening to the participant without any verbal interventions. As noticed in the previous section, a first inspection at the judges' videos revealed that the behavioral stream may be better characterized by a series of discrete behaviors than a continuous chain of movements. In our previous analysis, we segmented these discrete behaviors and defined "*irrelevant*" segment because they were not related to the interaction while listening. Within the 260 remaining segments, the vast majority were composed of a postural move leading to a large quantity of motion. Thus, we decided to focus on these seated postural moves for our virtual judge.
The motion synthesis of virtual humans can get increasingly complicated as more types of motions are added. The animation of hands for example is challenging, as well as motions inducing contacts in the real world: both need perfect alignment in the interaction and constrains with the virtual environment. To focus on what is of interest in our study (postural moves), we proposed to give to the virtual judge a standard posture which allow to avoid these difficulties.

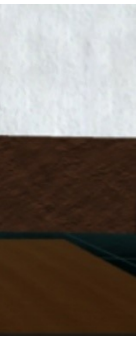

Figure 57: Front view of the virtual judge with face blurred and hand behind a laptop.

Seated behind a table, the virtual judge has its hand on a laptop, therefore hiding them from the participant in front of him. For the facial expression, we decided to place a blur filter following head movements. The purpose of this filter is to let visible the configural properties of the face (place of the eyes, mouth, etc) but reducing enough the information to disable the possibility to discern eventual facial movements (Figure 57). This posture might seem highly constrained, but as the average presentation lasts 3 minutes, it is totally credible.

In our previous study, we considered all significant postural moves of judges equally, making no differences between approach and avoidance for example. We take the same approach for the design of our virtual judge: the only variable we aim to control in purpose is timing, regardless of types of postural moves. However, we need to design various postural moves to give some variability to the virtual judge (variability is inherent to human movement and thus is part of credibility). To do that, we defined various possible postural moves in the 2D horizontal plane which depend on

the position of the virtual judge. We defined 7 possible postural positions (CENTER, FRONT, FRONT-LEFT, FRONT-RIGHT, BACK, BACK -LEFT, BACK –RIGHT) that the virtual judge can take and move from one to another (Figure 58).

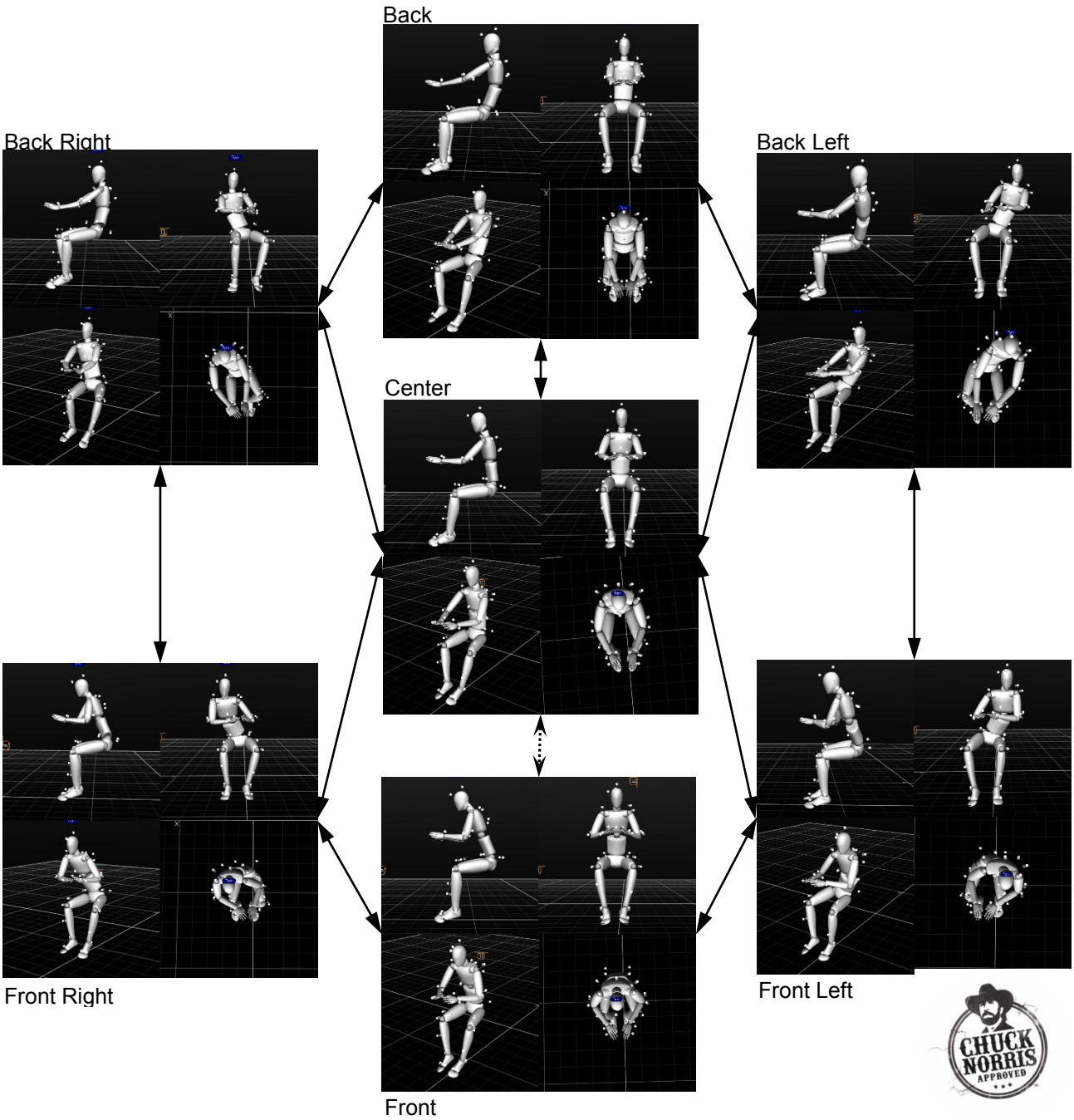

Figure 58: schematization of the 7 positions the virtual judge can take with the possible pathways indicated with arrows. Images are extracted from the motion capture software.

To further deepen the variability of the virtual judge, we defined two types of postural changes which correspond to significant moves of judges in our corpus:

- Transitions which are moves from one position to another
- Fidgets which are moves in the same position

Finally, when in a defined position not performing a fidget move or a transition move, the virtual judge is in idle move. This means that no significant movement is played but it still moves in a very subtle way to not appear as totally static.

All possible moves of the virtual judges were motion captured to ensure a high realism of seated postural moves. In each of the 7 positions, we captured 3 different fidgets. For each possible transition, we captured 2 moves in one sense (position A to position B) and 2 moves in the other sense (position B to position A). All these moves have duration ranging from 3 to 8 seconds. This provided the synthesis module with 69 possible postural moves. As in average a judge does between 4 and 5 significant postural moves within a presentation, this provided enough variability to avoid the perception of similar postural moves. Finally, in each position we captured two takes of 40 seconds of idles movements (doing nothing). Figure 59 shows the motion capture session and an example of motion capture takes for position Center and Front.

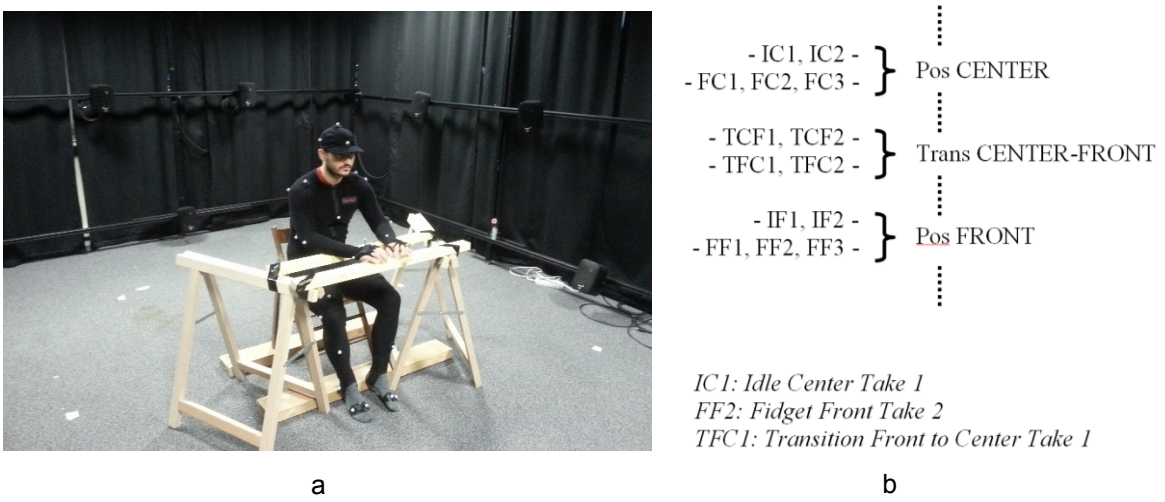

Figure 59: a) picture of me in motion capture suit in the mocap system. B) Example of motion capture takes for position Center and Front.

The virtual judge designed as such can be conceived as a state machine which has a set of possible motions in each position. The choice of the motion (the WHAT) to do is determined randomly with the only constrain to not play twice a motion during a presentation. The next step of the design of our virtual judge is to determine the timing of the motions (the WHEN). It will be the focus of our prediction analysis for the synthesis module.

6.2.2. Software architecture

As no evaluation is presented in this PhD thesis, we do not provide an extensive description of the software architecture. The architecture is composed of four main modules: a sensing module using the SSI framework (Wagner et al.), a synthesis module playing and interpolating the animations using the ADAPT framework (Shoulson et al. 2013), a rendering module developed in Unity and a decision module which link the sensing and the synthesis module to decide what and when to play behaviors as a function of user behaviors.

For the purpose of this application, the sensing module takes as input data from two devices to extract the same information as in the corpus. A Kinect in order to compute in real time the Quantity of Motion and Spatial Extent in the 2 D plane and a force plate to compute the 5 times series derived from the Center of Pressure displacements. The synthesis module takes as input the motion capture database described in the previous section.

The decision module is composed of two parts: a first part determine randomly without repetition which animation to play, and a second part which determine when to play this animation. The determination of the timing is the object of the prediction algorithm described in the next section.

6.3. Prediction of judges movements

The aim of this section is to present our prediction approach. This thesis being interdisciplinary, we purposely chose to keep our approach as simple as possible to make possible the study of all the components in one thesis. Machine learning and prediction is whole subject and our strategy is to propose a simple model which demonstrates the possibility to develop further such research.

6.3.1. Methodology

As no particular theory exist about how seated judges moves during a presentation as a function of interviewee presentation, the aim of this section is to develop a data-driven prediction algorithm which can determine the timing of sequential behaviors corresponding to postural moves based on our corpus. As described in the background section, the closest research domain to our prediction issue is the prediction of backchannels timing. The two main data driven approaches to predict these discrete behaviors are Hidden Markov Model (HMM which is a generative approach) and Conditional Random Field (CRF which is a discriminative approach) which are sequential probabilistic model providing real time probabilities of apparition of discrete nonverbal signals. In this approach, the prediction problem becomes the prediction of a binary feature: backchannel is present or absent. In a first step, probabilities of presence of the backchannel are predicted and then a decision is done, according to a threshold, about yes or not a backchannel should emerge. CRF have been shown to regularly outperform HMM in backchannel prediction.

Logistic regression is from the same family as CRF as it aims to classify event in two possible groups, but is simpler as it does not predict a sequence of discrete event as in CRF. Working as a simple regression, it provides as outcome a probability that the event belong to class A rather than class B. As a first approach, we use this probabilistic model to predict postural moves in our corpus. In our corpus, every QoM times-series for each judges is encoded as a series of 0 and 1, were 1 are identified segment of judges moves.

Machine learning model output probabilities of discrete event apparitions in real time. At each frame, to determine whether or not to play a behavior, a threshold is often empirically defined during the validation phase of the learning. The basic issue with this approach is that large individual differences exist in the output probabilities of these models, making this fixed threshold performing not consistently: for some individuals a lot of behaviors will be generated and for others no single behaviors will be played. An interesting approach to keep some consistency in behaviors prediction is the dynamical threshold method proposed in (Kok and Heylen 2013) which propose to modulate online the threshold as a function of time between responses. In our approach, we implemented both type of threshold for comparison purpose (fixed and dynamic). Equation 1 presents the dynamical threshold equation.

$$\text{Eq 1} : T_t = T_{tlast} + j - \frac{(t - t_{tlast})^2}{(g*r)^2} * \frac{j}{d}$$

T_t is the dynamical threshold determined at time *t*. Parameter *g* is the gap parameter which is the mean in seconds between two predicted listener responses that we calculated over the whole corpus. Parameter *r* is the sampling rate of the system, to convert seconds in frames (*t* is in frames). Parameter t_{tlast} is the time since the last event, and T_{tlast} is the dynamic threshold at that time. Parameter *j* is the jump parameter, which is the amount the dynamic threshold increase after the generation of a feedback. Parameter *d* is the drop-off parameter which controls how the dynamic threshold decreases over time. In our approach, *j* is fixed at twice the standard deviation of the output probabilities of training data, making of *d* the only parameter to adjust during the cross-validation phase. Interestingly, these variables and dynamic thresholds could be associated with individual dispositions (e.g., impulsive style). In our case and without studies available on the analysis of this kind of task, our ground truth is a random model which generate postural moves randomly following a normal distribution with mean and standard deviation of time between two postural moves calculated over the whole corpus.

Our prediction model development is composed of two main steps: first a feature selection (selection of relevant features to include in the model) and second the training and cross-validation of our model. Finally, we compare our models using various indicators, the F1 measure being the most commonly used.

6.3.2. Feature Selection

From our participant data in our corpus, we consider the 8 time-series used in the first part of this chapter and compute their first derivative (apart from QoM because Imp is already its first derivative), which gives us 15 time-series. From each time-series, 8 variables are computed (minimum, maximum, mean, standard deviation, energy, index of dispersion, mean power frequency, peak frequency) based on a time-window of 3 seconds to match our previous analysis. This provides us with a total of 120 variables computed at each frame in the corpus.

The first step of our feature selection is to remove redundant variables: after computing all possible pair-wise correlations between variables taking the whole corpus, one variable of every pair correlating above 0.8 is removed. Following this procedure, 35 variables are removed.

The second step is to perform a forward sequential feature selection: variables are added sequentially to the model based in the best possible model at each step. At step *i*, the algorithm test all possible model *i+1* which is composed of the model *i* plus one variable. The variable which decreases the most the deviance of the fit is kept and the algorithm goes to the next step. This approach enables a ranking of all our variables. In our cases, the model is a logistic regression cross-validated using a 10 fold approach. The decrease in deviance of fit (twice the difference between the maximum achievable log likelihood and that attained under the fitted model) while including more variables is presented in Figure 60. From this curve, we decided to keep in our model the 30 best variables which present a trade-off between parsimony and variance explained.

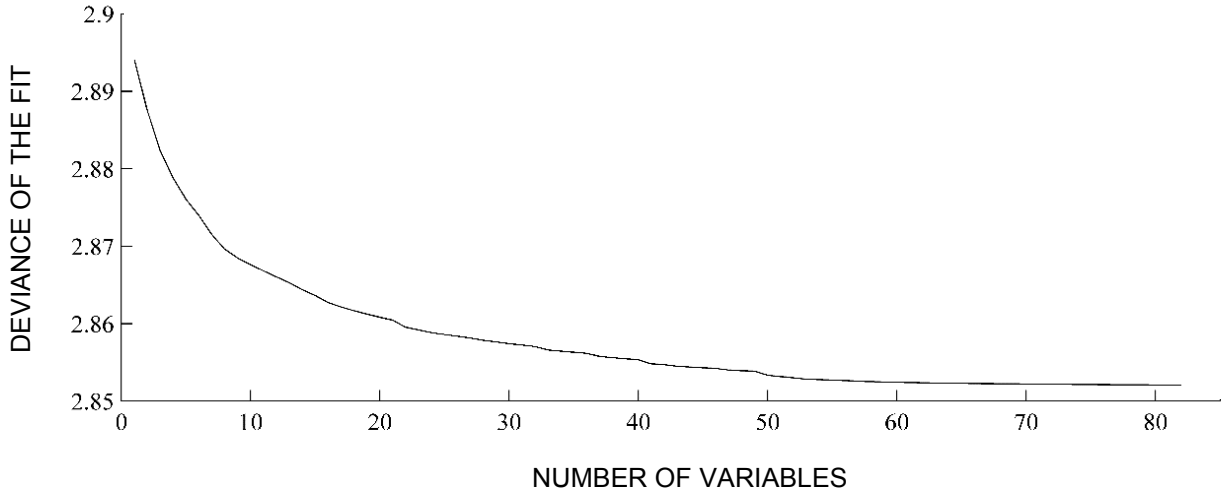

Figure 60: Decrease in deviance of fit while including more variables.

6.3.3. Prediction experiment

For the training and evaluation of our prediction model based in the 30 variables selected, we followed a classical train-validation-test procedure. First all the presentations are separated in 10 equal classes. At each step of the 10 folds, one fold (3 presentations) is kept for testing purpose and the rest is used for training-validation. The training-validation

phase is done with a hold-out procedure training our logistic model on 2/3 of the available presentations (18 presentations) and validating on the remaining 1/3 presentations (9 presentations). During this step, the thresholds (fixed or dynamical) are adjusted to maximize the F1. This procedure is done four times to evaluate our four possible models: with a fixed threshold or a dynamic threshold and with or without individual differences as predictors. F1 scores is the weighted average of the precision and recall, where precision is the ratio of true positives by all positives (good selected items over all selected items) and recall is the ratio of true positives by all false negatives plus true positives (good selected items over all good items).

In this experiment, we consider as true positive any predicted postural moves (intersection between the dynamic threshold and the outputted probabilities) which is within a segment from the corpus, and without other postural moves already predicted within the 3 seconds before the current prediction.

Figure 61 shows the result of the prediction algorithms.

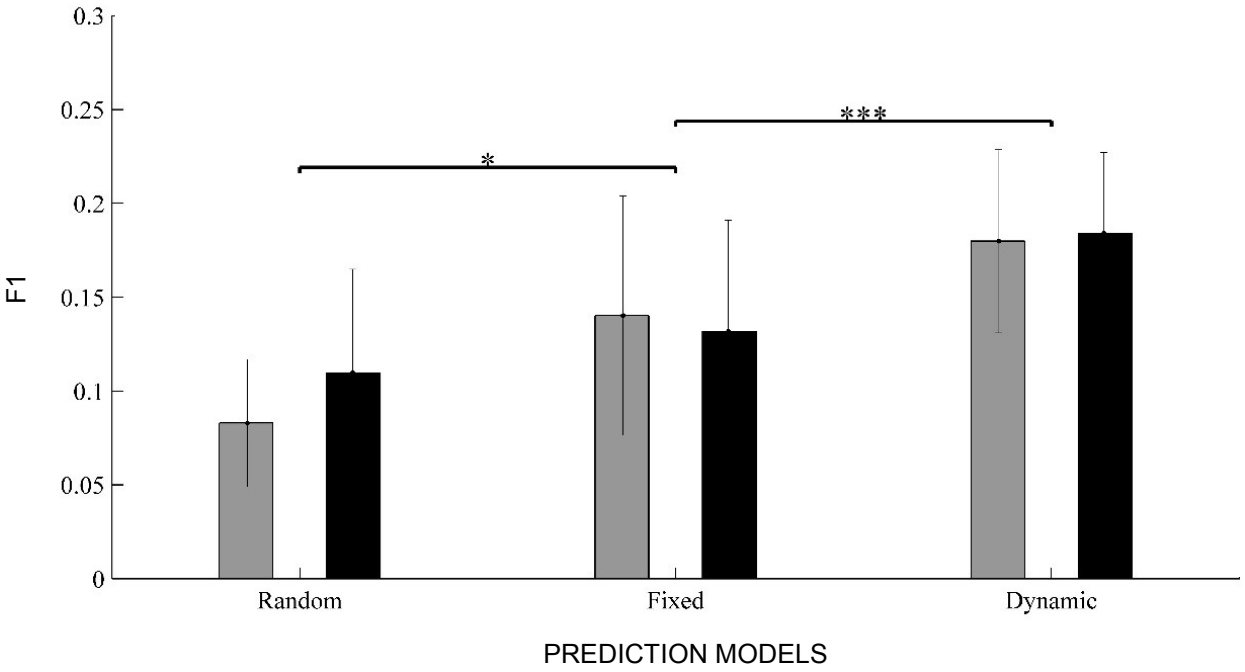

Figure 61: result of the prediction algorithms

Figure 61 shows the comparison of our models with fixed and dynamic threshold over the random condition. Fixed threshold perform better than the random condition ($t(19) = -2.2102$, $p = 0.040$) and dynamical threshold performed better than fixed threshold ($t(19) = -4.1708$, $p<0.000$). The inclusion of individual differences in the models did not affect the performance. For more details about these predictions, Table 34 presents more information about the three models (Random, Fixed and Dynamical) without individual differences.

	F1	Recall	Precision	T Dispersion	Nb moves	Sd moves	Length	Sd length
Random	0,083	0,082	0,086	0	3,675	2,115	1581	1661
Fixed	0,14	0,449	0,087	0,206	20,42	10,725	799	1038
Dynamical	0,18	0,392	0,124	0,995	13,904	5,074	603	1113

Table 34: Detailed results of each type of threshold for the prediction algorithm

The dynamical threshold model performs better in terms of precision, and provides more consistency in number of moves per presentation, based on postural and overall movement variables of the participant. In comparison, the fixed threshold predict more moves but at the expense of precision. However, one drawback of the dynamical approach is the dispersion of the threshold which is much bigger. This means that the equation parameter of the dynamic threshold is not stable across participants, requiring to be adapted to each participant. Even if better than the fixed threshold, another issue is the still large number of moves (13 compared to the 4 of the ground truth): such an active virtual judge would appear unrealistic. Thus future works should aim at improving the timing as with the dynamic approach we used but also respect the average number of moves per session.

The fact that the inclusion of individual differences in the model did not improve the performance is not so surprising: judges' personal characteristics instead might have helped as we are predicting the judges' body moves.

6.4. Limitation and future works

In this section, we presented the various components of the development of a virtual interviewer. We defined the judged position in order to advantageously focus on postural moves which were the key behaviors in our precedent analysis. Software architecture was proposed and a motion capture session performed in order to aliment the motion synthesis module. The key aspect of our interactive judges is that its animations are varied but of only one type: postural moves. This will enable the subtle animation of the virtual judge while keeping a high degree of control over other variables. Finally, the interactive part of the judge was proposed to be implemented in a data-driven approach: following methodologies defined in the development of backchannels, we developed a simple preliminary prediction algorithm which demonstrated to perform better than chance.

The mains limitations of our approach resides in the basic prediction approaches. All these limitations are rather seen as potential improvement in the near future development of an optimized prediction algorithm:

- Use of Condition Random Field instead of logistic regression in order to predict sequence of event rather than single events
- Use of a regularization step (via a lasso approach for example) in order to prevent from over-fitting. Such a step might lead to lower individual differences in the output probabilities
- Investigate several approach to link participant nonverbal behaviors and the binary outcome of body moves as in (Morency, Kok, and Gratch 2010)
- Model explicitly the idiosyncratic aspect of postural moves of judges. In fact, contrarily to backchannels which are inherently interpersonal, postural moves exist even in individual context caused by the discomfort of a static posture. Jointly modelling this effect and the influence of participant behaviors might help to get more consistent results
- Investigate alternative ways of taking into account participant individual differences. Random intercepts could be including in the model or clusters of participant according to their interactional styles might help improve the algorithm performance

7. SUMMARY AND PERSPECTIVES

In chapter 1, 2 and 3, we began this PhD thesis by questioning the link between individual differences and interpersonal bodily processes at a general level. Such an a-contextual conceptualization provided elements of description of an individual relating differentially to others in a standard, universal environment. In this chapter, we attempted to confront our hypotheses to a real case study with interpersonal processes: a job interview.

The job interview task is gaining interest in both Human Sciences and Computer Sciences, the economic crisis context fostering this effect. In the former domain, scientists have standardized the task as an experimental tool to assess the effect of stress on individuals. The protocol – the Trier Social Stress Test (TSST) (Kirschbaum, Pirke, and Hellhammer 1993) – has been used to investigate physiological reactions or coping strategies while facing this demanding situation. In the later domain, scientists attempt to model an intelligent virtual interviewer which could engage an interviewee in order to help him/her perform better. Researches focus on emotional inferences, dialog turns and complex theory of mind simulations. To our knowledge, no studies from both domains asked the question of the importance of low level interpersonal bodily processes in this task. This appears not surprising considering that almost all the literature studying interpersonal bodily processes do so in affiliative positive context (e.g., studies dealing with rapport), when individuals wish to get along with others. Motivated by the idea that low level social interactions are pervasive and primary to more complex social cognition phenomena, this chapter presented a detailed analysis of a job interview corpus.

A multimodal corpus of job interviews was collected in the context of a collaborative project where participants were facing two interviewers at a time. Participants were standing and the two assessors seated. Our literature review highlighted the essential role of dynamic postural control in coordination and affect. The advantage of measuring postural control via a force plate is that it can be hidden from the view of participants and not impair the ecological validity of the setup. They are very precise and with proper post-treatment can give information about smooth macro movements but also very subtle aspect of postural control such as postural stiffness. In addition to this force plate, we placed two video cameras: one facing the participant to capture the overall activity and one facing judges to capture their overall activity.

The collection and analysis of this corpus was motivated by an interdisciplinary goal: contributing to the development of virtual judges for training application as well as moving toward a proposition of a virtual judge as an experimental tool. Rather than limiting negatively the investigation of each line of research, such a joint approach operates a positive constrain which encourages the merging of methods and perspectives. A primary necessity to the design of valid experimental tools is to model the interaction based on real data. Interestingly, recent modeling approaches from Computer Sciences move toward such data driven methodology and confirmed our interest in the collect of naturalist data. The corpus protocol included several phases: we focus on the presentation phase where the participants present themselves to two interviewers. This asymmetry enabled to limit the scope of the analysis to expressive behaviors for participants and listening behaviors for judges, avoiding any verbal interaction which complicates significantly the clear analysis of nonverbal phenomena. As a remark, the original TSST protocol does not include feedbacks phases to focus on the effect of the mere presence of judges.

One fundamental aspect of job interviews is their emotional nature: arguing about one's own qualities in front of two interviewers, the judges' eyes become a direct source of ego-threat. This aspect has two implications: first in average all participants are aroused by such a situation and second each individual is differentially affected by such a setup depending on various individual differences. To account for this effect, we had to reformulate our hypotheses. Within the four studied individual differences – neuroticism, extraversion, agreeableness, affective alexithymia –, only agreeableness seems to not directly interact with the situation: neurotic individuals have low self-esteem and have a

heighten fear of rejection, extrovert individuals have a general positivity partly due to their enhanced trust in others and affective alexithymia impairs the regulation of emotion leading to overwhelming arousal level.

The fact that we have an interdisciplinary goal is the reason why we presented in this chapter both explanatory experiments and prediction analyses. After the presentation and validation of the corpus, we organized our analyses by grouping studies made at the individual level and studies at the interpersonal level. In the individual section, we evidenced that the bodily signature of participants was associated with individual differences (excepted agreeableness) and perceived performance (discomfort and motivation). While both neuroticism and affective alexithymia revealed a coherent pattern of postural freezing, extraversion was unexpectedly associated with smaller and smoother behaviors. We re-interpreted the effect of extraversion as a greater detachment from the situation, in accordance with the similarities of the independence aspect of dominance. Perceived discomfort was explained and predicted by posture related variables and perceived motivation by overall activity variables. Considering all the limitations associated with our evaluation procedure of these two perceptual aspects, these results encourage to further push the development of a task performance prediction module. Also, no direct associations were found between individual differences and perceived performance which appear intriguing given the previous results. Further analyses with more multivariate approach could enable to uncover interaction patterns impacting overall perceived performance. Lastly, self-report states and task performance were marginally associated with bodily signatures, although related to individual differences. The reflective aspect of these self-reports might be associated with more high level aspects of individual differences. The investigation of other emotion evaluations such as peer observations or physiological measures could help to disentangle this issue.

In the interpersonal section, the presence of low level bodily adjustments was evidenced by two different analyses: mutual bodily behavior changes and interaction synchrony. This first result is the primary evidence of the pervasive position of nonverbal coordination processes: they occur even in drastically constrained setup and should be studied in a more systematic way. The functional role of these coordinations in our job interview task is yet to be studied but we hypothesize that an interviewer rightly bodily tuned to the interviewee is a key aspect of the interview realism and success. The development of a virtual judge based on this corpus will aim to study such questions. The selected individual differences were associated with these interpersonal processes although the correlations were low (about 0.35 in average). Neuroticism and affective alexithymia were associated with more contraction during judges' moves confirming the postural freezing hypothesis but showed different patterns of synchronization: neuroticism was associated with weaker synchronization and alexithymia with greater postural synchronization lag. Both could be interpreted by the mediation of arousal, neuroticism being associated with greater levels and alexithymia with impaired regulation. Extraversion tended to be associated with general synchronization lag in accordance with a detachment hypothesis. Agreeableness did not influence synchronization as expected in such non-affiliative context. The combination of arousal based and motivation based interpretation of our results appeared complex and perhaps too tentative. Future research could be attentive to the development of new integrative theories of self-regulation which would limit such confusions. Also, dealing with the concordant effect of multiple phenomena is common aspect of naturalistic setup: the analysis of reality is necessarily confusing. A promising line of research to disambiguate our results is to articulate our different analyses: taking into account individual differences at the individual level (more or less stable individuals, more or less active individuals, etc) with the individual differences at the interpersonal level (also taking into account the interactional style).

The design of a virtual judge presented in the last section attempted to capture the subtle interactive process highlighted earlier. Defined seated, its hands behind a laptop, the virtual human principally operates postural moves which are adjusted in time in order to take into account participants bodily behaviors. Such a minimalist modeling is credible given the nature of the task (application driven) and enables the fine control of behavior to perform experimental studies (experimental tool driven). A prediction algorithm inspired by the backchannel literature in HCI proved to perform better than chance in the postural moves timing prediction. The approach being basic in nature, future works

have many ways to improve these performances encouraging the continuance of the project. The main criticism which could be made to our approach is the lack of mutual coupling in this model: the postural moves of the virtual humans are modeled as mere reactions to participants' performance. The fact that the overall synchrony between participants and judges occur at lag 0 suggests a coupling mechanism rather than a reactive, a kind of mutual entrainment process. However, the discretization of judges' behaviors makes this conceptualization difficult: outside postural moves, the judges are supposed immobile. An interesting future line of research could look at such mutual entrainment processes: emerging synchronization could or could not result in a postural move of the judges as a function of dynamic resonance for example.

CHAPTER 5

Case study 2:
Fitness coach

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The sport activity of following fitness coach energetic movements is now common practice in fitness gym or at home via videos. Most of the time considered as a one-sided interaction where the coach performs a movement sequence and the pupil follows, this social interaction made of a predefined movements requires subtle timing adjustments and the enhancement of motivation and engagement. The concordance of the development of home interactive exercises devices (Wii) and the growing health risk of obesity and lack of physical activity foster the research interest in home exercises application. While the Computer Sciences community generates a prolific literature about the design of exergames, mobile coaches and physical data visualization applications, Human Sciences research mostly concentrate on the evaluation and the acceptance of such new technologies for different population (e.g., obese or elderly). These technologies can help individuals with impaired social acceptance in their transition toward more externally oriented activities. However, very few studies investigate the subtle dynamic of a coach coupled with a pupil, overlooking the power of low level interpersonal bodily processes. In this chapter, we present our analysis of the dynamical and social coupling between pupils and coaches. After reviewing recent works specifically related to this case study, we present our approach, method and collected corpora. By focusing exclusively on the mutual performance of a predefined movement sequence without verbal exchange (and discarding the role of gaze), we reduce the scope of the research: we can focus on the timing of the movements as well as their expressivities, also called movement qualities.

The analysis of this task is done in two steps. First, the coaches' movement expressivity is analyzed based on a motion capture corpus of coaches moving individually under various emotional contexts. Both the objective computation of movement qualities and the subjective perception of such motions are studied and compared. This analysis contributed both to the understanding of impression formation about personality and affect and the synthesis of stylistic fitness motion sequences. The second analysis deals with the understanding of the synchronization patterns associated with an explicit following/follower fitness task. To do so, a second motion capture corpus was collected with coach-pupil dyads performing the same motion sequence as in the first study. As for the first analysis the aim is twofold: providing a better understanding about the role of interacting bodies in such a constrained setup and lay the ground for the modeling of a data-driven interactive coach. Particular attention will be paid in how individual differences are related to the interpersonal bodily adjustment. The last part presents a first attempt toward such virtual fitness coach.

1. FITNESS COACH: RELATED LITERATURE

1.1. Virtual sport trainers

1.1.1. Exergames, virtual trainers and health

Sports interactive applications are now flourishing. The rapid growth of affordable sensing technologies for the entertainment industry enabled the development of physically engaging games – the so called exergames. As the lake of a daily physical activity is one of the main health risk factor, health scientists are gaining interest in this new field. Exergames can be used to persuade seniors to increase physical activity (Brox et al. 2011), or integrated in physical education courses (Staiano and Calvert 2011) and help combat obesity (Lyons et al. 2012)(Staiano, Abraham, and Calvert 2012)(Lamboglia et al. 2013). Following the taxonomy proposed by (Buttussi, Chittaro, and Nadalutti 2006), virtual trainers are sport applications different from exergames in their explicit purpose: training to improve fitness. They can propose a personal fitness program, provide performance feedbacks and motivational supports (Lowe and ÓLaighin 2012). Energy expenditure is associated with user enjoyment in the case of exergames (Lyons et al. 2014). More generally, enjoyment has been shown to be a predictor of physical exercising (Dacey, Baltzell, and Zaichkowsky 2008) entraining the development of a specific scale for the measurement of enjoyment of physical activity (Mullen et al. 2011). Althought several authors have emphasize both the role of the affective experience

(Raedeke 2007) and motivational support (Resnick et al. 2002), for most fitness trainers the activity seems assumed to be intrinsically motivated (Mullen et al. 2011).

1.1.2. Virtual trainers in HCI

The label "*virtual trainer*" encompasses a wide variety of applications. However, systems for full body movements training and evaluation are scarce. Virtual PAT was one of the first system with video based movement tracking enabling the TV coach to provide appropriate feedbacks (Davis and Bobick 1998). (Babu et al. 2005) proposed a framework for exercise monitoring based on 3d colour markers. Both were early successful proof of concepts which do not inform about the user experience. Some recent works such as YouMove (Anderson et al. 2013) or MotionMA (Velloso, Bulling, and Gellersen 2013) focus on guiding users in movement training by providing corrective feedbacks (Figure 62). In this line of research, researchers move on the proposition of patient oriented application in order to improve rehabilitations programs (Tang et al. 2014).

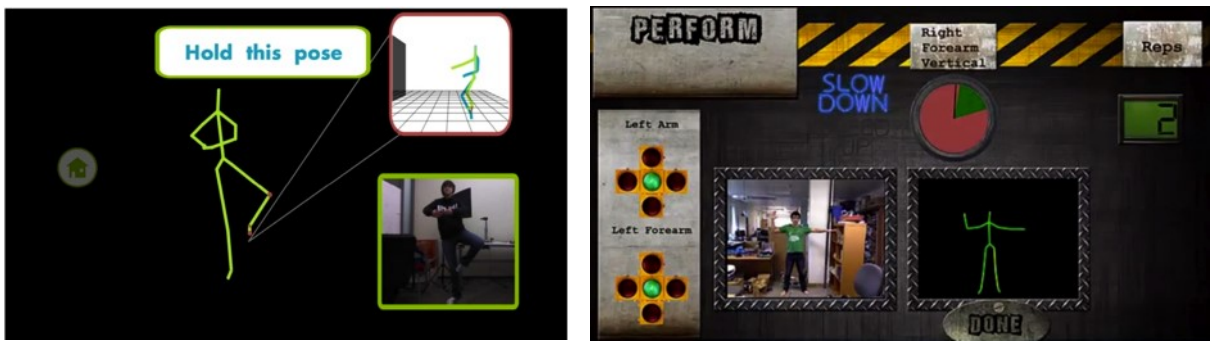


Figure 62: a) application YouMove (Anderson et al. 2013) b) application MotionMA (Velloso, Bulling, and Gellersen 2013)

Besides these direct movement feedbacks applications, the trainer proposed by (Bleser et al. 2013) enables the design of a personalized program. All these systems do not consider enjoyment, affect or motivation. Perhaps the most comprehensive attempt to design a virtual trainer is the Reactive Virtual Trainer project (Ruttkay and Welbergen 2008). It included the monitoring of emotional user states as well as emphatic feedbacks to keep the user motivated. Unfortunately, no user studies are available on these particular aspects. One recent study focused on motivation aspects for virtual coaching: (Frost, Boukris, and Roelofsma 2012) show how parasocial interaction is related to intrinsic motivation. Simple movement guiding without personal feedbacks such as compliments had no effect.

1.1.3. Movement predictability

The study of online synchronization between sports coaches and pupils is an overlooked research topic in Human Sciences. A large literature exists about the relationship coaches build with their athletes, including personality, attitude and affect determinants of the relationship quality (Jackson et al. 2011). But this approach focuses on long term connectedness and is of little help in the case of online interaction with unfamiliar fitness coaches.

A totally different line of research of particular interest in the case of coach-pupils fitness interactions deals with how individuals make them predictable in order to be followed. Coming from joint action research, (Vesper et al. 2011) studied first how interpersonal coordination was improved thanks to strategies to make oneself more predictable. In a minimalist experiment, they evidenced that the strategy to reduce movement variability significantly enhance the subsequent coordination. Other strategies such as emphasizing key frames of the movement (e.g., angle changes) are

also at play. Altogether, these authors called these signaling strategies "*coordination smoothers*". (Sacheli et al. 2013) completed this study by explicitly studying the difference of role – leader versus follower – on the emergence of these coordination smoothers. They evidenced that only leaders did so.

1.2. Kinematics and movement qualities

In addition to be dynamically coupled with the pupil, the fitness coach pervasively conveys affects, attitudes and personalities through his/her motion quality. The communicative value of movement qualities has been studied with several approaches coming from different scientific backgrounds. The first subsection below aims at reviewing these varied origins and providing more details for the approach used in this chapter: the effort-shape (Dell 1977) analysis method of the Laban notation system. The following two subsections survey works on associations between movement qualities and two social phenomena that are important for modeling a virtual full body coach: emotion and personality. Both kinematic patterns of bodily expressions and perceptions of emotion and personality are reviewed. Interactions between observed personality and emotion (whether expressed or perceived) are discussed because the overall impression made by the observer is often a merging of both dimensions. The last subsection considers essential methodological aspects when studying the perception process from bodily expression to perceived social cues.

1.2.1. Communication through movement qualities

Nonverbal communication involves different channels such as voice, face, body and touch (App et al. 2011). Bodily behaviors are themselves decomposed into different types of cues. For a long time, gestures as specific isolated movements with a clear onset and offset (Kendon 1994) and postures as static full body geometrical configuration (Bull 1987) have been at the heart of bodily communication research (Dael, Mortillaro, and Scherer 2012). Common to both typologies is the process of forcing a continuous behavior into a series of discrete events (Grammer, Filova, and Fieder 1997). An alternative option is to embrace the analog dynamics of human behaviors. Movement kinematics can be defined as "*the way in which human movements are executed with respect to the dimensions of time and space*" (Wallbott 1985). "*How*" the movement is performed is not necessarily "*expressive*", which implies an intention to communicate, but is rather "*distinctive*". The contribution of motion alone to the communication of social cues has been evidenced with point-light displays developed by Johansson (1973).

Movement quality is the subjective description of the objective measure of human kinematics often related to its inner dynamics (Runeson and Frykholm 1983). One approach for studying movement quality has been to analyze semantically the subjective kinematic descriptions of behaviors (Wallbott 1985) (Gallaher 1992) (Shikanai, Sawada, and Ishii 2013). These works revealed remarkable consistencies in their results with a recurring four-factor structure. These movement quality dimensions are space (or expansiveness, expansion), intensity (or expressiveness, dynamics), fluency (or coordination, stability) and hastiness (or animation). Structural approaches propose notation systems adapted for the detailed description of movement dynamics (Birdwhistell 1972), (Sheets-Johnstone 1999). The notation system proposed by Laban (1950) has been used in dance studies and more generally in studies of bodily expressive communication. The Laban movement analysis (LMA) framework is composed of four main categories (body, effort, shape and space) that qualify the body in movement with respect to inner intentions. The effort-shape subdomain has received considerable interest as a systematic way of describing body configurations and movement qualities (Dell 1977) (Levy and Duke 2003). Effort is composed of four bipolar components including space (indirect/direct), weight (light/strong), time (sustained/sudden) and flow (free/bound). Space refers to "the way the body sculpts itself in space" (Laban 1950). Shape flow, its first component, relates to the form of the body itself (growing or shrinking). The other two components, directional change and shaping movement, characterize the attitude toward an external object. Interestingly, the Laban conceptualization is not so different from the

experimental results from semantic studies. They all include not only kinematic descriptions of motion but also perceived dynamic properties. Because human kinematics inherently reveal its underlying dynamics, the human observer tends to directly perceive the causal aspect of movement: for example, we perceive the effort behind the movement of man lifting a heavy load (Runeson and Frykholm 1983).

Several quantifications of these movement qualities have been proposed. In a seminal work, Camurri, Lagerlöf, and Volpe (2003) proposed a quantification of the Laban effort domain based on computer vision algorithms. Space, weight, time and flow were inferred based on automatically computed activity and expansiveness time series extracted from video. Other solutions for the effort-shape systems have been proposed (Samadani et al. 2013), (Dyck et al. 2013) in addition to quantifications based on Wallbott's (1985) or Gallaher's (1992) works (see (Pelachaud 2009) and (Glowinski et al. 2011)). All of these quantifications are based on kinematic variables. An understudied research question is the validation of the correspondence between the quantifications (e.g., computed fluency) and the perceived movement qualities (e.g., perceived fluency). Several early works reported good correspondence between perceived and actual movement qualities (McGowan and Gormly 1976) (Wallbott 1985). Only one paper examined this question with modern quantification tools (Samadani et al. 2013). The comparison between manual annotation by a certified movement annotator and the computed movement qualities revealed a high agreement across the effort-shape domain for acted arm movements. The associations between untrained observers' ratings and quantified movement qualities in a wider variety of movements remain to be studied. In the following sections of the chapter, we make the distinction between perceived movement qualities as proximal percepts and computed movement qualities as distal cues (Scherer 1978), (Scherer 2013).

In summary, movement qualities are subjective descriptions of the motion dynamics based on kinematic information that convey social cues. They can be described with a few dimensions. The Laban effort-shape system offers a way to systematically characterize them. Kinematic quantifications have been proposed, but their correspondence with non-expert human observations remains to be studied. The great potential of movement qualities as a communication modality relies on this direct perception of other inner forces and constrains (dynamics) and their potential associations with intentions (tendency to act) and emotions.

1.2.2. Movement qualities and emotion perception

An emotion can be defined as "*an episode of interrelated, synchronized changes in the state of all or most of the five organismic subsystems (cognitive appraisal, bodily symptoms, action tendencies, expression and feelings) in response to an evaluation of an external or internal stimulus event as relevant to major concerns of the organism*" (Scherer 2005).

Although we usually refer to emotions as states, the affective process is a *changing state* and is therefore dynamic. Sheets-Johnstone (1999) explains the relation between emotion and movement by the congruency of their qualitative dynamics. The main theoretical framework used to predict motion-emotion congruencies is action tendencies (Frijda 1986). Mainly described as discrete phenomena, emotions can alternatively be studied with dimensional approaches (Scherer 2010). Valence (intrinsic pleasantness of the emotion-eliciting object), arousal (degree of physiological activation) and potency (individual's sense of control over the emotion-eliciting event) are the principal axes used. These dimensions have been shown to meaningfully explain differences in affective bodily expressions, even when the protocol is aimed at eliciting categorical emotions (Dael, Goudbeek, and Scherer 2013).

Previous studies have shown that movement qualities such as *proximal percepts* (perceived movement qualities) are associated with emotion recognition. At a general level, Atkinson et al. (2004) showed that the perceived exaggeration of acted movements increases the emotion perception accuracy and perceived emotion intensity.

Authors supposed that this general qualitative evaluation was driven by speed and expansiveness. Using sign language, Hietanen, Leppänen, and Lehtonen (2004) demonstrated the importance of movement qualities for emotion recognition. The association between high emotional arousal (interchangeably called activation (M. M. Gross, Crane, and Fredrickson 2010), intensity (Atkinson et al. 2004) or emotion quantity (Wallbott 1998)) and a combination of high velocity, energy, force, directness and expansiveness is a recurrent finding (Wallbott 1998), (J. Montepare et al. 1999), (M. M. Gross, Crane, and Fredrickson 2010), (M. M. Gross, Crane, and Fredrickson 2012), (Dael, Goudbeek, and Scherer 2013), (Crane and Gross 2013). This has been attributed to the physical effort mobilization or the state of readiness to act provoked by a high arousal (Frijda 1986). Discrimination of emotions according to valence is less consistent across studies. Fluency has been found to differentiate anger (less fluent, jerkier) from elated joy (more fluent) (J. Montepare et al. 1999), (Dael, Goudbeek, and Scherer 2013). Other studies highlight the role of expansiveness, which is greater for elated joy than for sadness (M. M. Gross, Crane, and Fredrickson 2012),(Crane and Gross 2013). In terms of action tendencies, a negative feeling is observed to be associated with the tendency to flee, whereas a positive feeling is related to free activation (Frijda 1986). This is a non-specific motor response, and it probably participates to the difficulty in recognizing it (Fredrickson 1998).

Works based on movement qualities as *distal cues* (kinematic cues) demonstrated a similar pattern of results. With movement purposely performed with different movement qualities, Meijer (1989) distinguished three dimensions: rejection-acceptance related to strength and directness of the movement, withdrawal-approach associated with moving inward or outward, and preparation-defeatedness (associated with surprise) related to sudden, fast and direct movement. Arousal is consistently associated with velocity and acceleration (Pollick et al. 2001), (Glowinski et al. 2011), (M. M. Gross, Crane, and Fredrickson 2012). Glowinski et al. (2011) found that in cases of high arousal, jerkiness is enabled to distinguish between negative and positive emotions. Even if the clustering algorithm defined by these authors performed well, the pattern was less distinctive for low arousal emotions. When emotion was induced in dancers, happiness-related expressions were observed to be expended more and were more impulsive than expressions of sadness (Dyck et al. 2013). Kinematic patterns of bodily expressions of emotions have often been studied with gait analysis. Speed often came out as a main discriminative feature (Roether et al. 2009). Other critical features proposed are specifically based on gait biomechanics models and, therefore, are not interpretable in terms of movement qualities (Barliya et al. 2013).

Whether distal or proximal, movement qualities have been shown to be related to emotional dimensions. High arousal is consistently associated with more energy and speed. Differences in valence show a less evident influence on movement qualities and are probably more dependent on the task. One possible issue is the interaction with the arousal dimension: valenced bodily expressions are different under low or high arousal emotions, with high arousal being easier to discriminate than low arousal valenced emotions. Finally, most of these studies are based on actors instructed to portray emotions. While it ensures high recognition rates of emotional movements, it also limits the applicability of the results to real word situations (M. M. Gross, Crane, and Fredrickson 2010).

1.2.3. Movement qualities and personality perception

Personality traits describe individuals' invariant characteristics across both time and situations. While several models have been proposed to capture people traits, the five-factor model of personality has been shown to be the most robust (Costa and McCrae 1992). This model characterizes an individual's personality across five broad traits, namely, extraversion, agreeableness, conscientiousness, neuroticism, and openness to experience (John, Donahue, and Kentle 1991).

Personality traits have been observed to be visible in nonverbal behaviors whether self-reported or judged by others. The self-reported trait most assumed to be linked to nonverbal behaviors is extraversion (Gifford 1991) (La France,

Heisel, and Beatty 2004). Often associated with more energetic and expressive behaviors, extraversion is consistently associated with cheerful expression (Hall et al. 2008). This is coherent with the description of extrovert people as impulsive and uninhibited individuals (John, Donahue, and Kentle 1991). Other traits may have a more contextual influence on nonverbal behavior: agreeableness will influence behaviors in a social context (Berry and Hansen 2000). Neuroticism will modulate reactions in situations that induce negative affects (J. J. Gross and John 1995), (Riggio and Riggio 2002). Few studies analyzed the association between self-reported personalities and their associated bodily kinematics (distal cues). Naumann et al. (2009) found extraversion associated with energetic stances and with agreeable and emotionally stable people standing in a more relaxed way. Using a music-induced movement paradigm, Luck et al. (2010) found that extraversion and neuroticism were the two traits most related to body movement variables. They conclude to a concordance with the literature that extroverts are energetic and expressive, whereas neurotic people display reduced, localized and jerkier movements.

Judged personality has also been studied in relation to perceived movement qualities (proximal percepts). Studying political speech, Koppensteiner and Grammer (2010) show that agreeableness is associated with a low level of activity and variability in verticality movements, extraversion with high activity and small movement fluctuations, and openness to experience with movement direction changes, and finally that neuroticism was associated with smooth transitions. These findings were confirmed in a subsequent study with a different protocol (Koppensteiner 2013). During gait analysis, movements were reduced to two components evaluated on the effort-shape domain of the Laban notation system (Thoresen, Vuong, and Atkinson 2012). Agreeableness, extraversion and openness were positively associated with perceived spatial extent. Neuroticism was negatively associated with indirect, sustained and relaxed movement qualities. In all of these experiments, reliability was good, confirming the consensus at zero acquaintance (when observers have no prior knowledge of the person) from movement kinematics only. The two consistent findings emerging from these studies (perceived extraversion associated with movement activity and perceived neuroticism associated with movement jerkiness) are coherent with the literature on self-reported personality (Riggio and Riggio 2002). However, having personality impressions based on good general rules (e.g., extroverts have energetic movements) does not necessarily lead to accurate judgment. When general physical appearance is available, only extraversion is accurately judged from the energetic stance (Naumann et al. 2009). With only gait kinematics available, no associations between perceived and actual personality ratings were found (Thoresen, Vuong, and Atkinson 2012).

While personality judgments have been observed to be strongly influenced by emotional expressions and evaluation of faces, only one study provides information regarding this phenomena for movement kinematics (Thoresen, Vuong, and Atkinson 2012). Perceived positive valence was strongly associated with adventurousness, extraversion, trustworthiness and warmth, and perceived high arousal was moderately correlated with adventurousness, extraversion and neuroticism. This phenomenon has been called *temporal extension* (Zebrowitz, Kikuchi, and Fellous 2007) or *overgeneralization* of emotional cues (J. M. Montepare and Dobish 2003).

Overall, self-reported and judged personalities have been shown to be related to movement qualities (distal or proximal) but without any evidence of accuracy. Observers form reliable and coherent social perceptions regarding the target person but misinterpret these available cues, merging personality traits and emotional dimensions via an overgeneralization process.

1.3. Perceptual framework

Studies on nonverbal behaviors often analyze the different components of the perception process separately: people states and traits, bodily expressions, perceptions of bodily expressions and people states and traits. To account for the whole process, some research paradigms have been proposed to structure the domain. The Brunswikian lens model is

by far the most widely used (Brunswik 1956). From the point of view of the observer, it is composed of three variables: a *distal psychological variable* (e.g., a self-reported personality trait) and several *available cues* (e.g., nonverbal behaviors) from which a perceiver makes an imperfect evaluation (e.g., perceived personality) of the distal variable (*evaluated criterion,* e.g., the self-reported personality trait). The gap between the *distal psychological variable* and *available cues* is called the *ecological validity*. *Cue utilization* is the association between *available cues* and *evaluated criterion*. Accuracy, which is the correlation between the *distal psychological variable* and *evaluated criterion*, is called *achievement*. Several of the studies reviewed in this section refer to this model directly to structure their analysis (Gangestad et al. 1992), (Bernieri et al. 1996), (Naumann et al. 2009). An extension of the model (Scherer 2013) proposed by Scherer (1978) contrasts the *available cues* from the Brunswikian lens into *distal cues* (measured and quantified cues) and *proximal percepts* (evaluation of cues). This distinction build on that as for distal psychological variables (e.g., a self-reported personality trait), the physically quantified behavior is not directly accessible to the observer eye (i.e., it is a distal cue). This part of the analysis is called *perceptual representation*. Interestingly, this last framework was used in the review from (Alessandro Vinciarelli and Mohammadi 2013) to structure their survey. The perceptual study presented in the following is structured following this approach.

1.4. Conclusion

As for the chapter 4 on job interviews, this review of the literature focused on the case study appeared to be complementary from the more contextually general state of the art of chapter 2. Although the literature about online bodily interaction between a coach and a pupil is scarce, we identified some interesting point to guide our analyses. First of all, the research context is favorable for the study of such task: the societal challenge is important and research projects about physical exercises at homes (i.e., exergames) are flourishing. But research projects consistently overlook the subtle mutual adjustments pervasive to any social interaction, as it was the case for virtual job interviews.

From the Human Sciences, we identified the importance of motivational support to enhance energy expenditure during physical exercises. Another particularly important aspect is the signaling strategies employed by individual leading a joint action (i.e., as our fitness coaches): they reduce their variability and provide key signals to guide the follower.

The second part of our survey provided a detailed review of the communicative value of movement qualities: defined as kinematic specifications of internal dynamics, they are closely related to individual internal states. The systematic study of their associations with social phenomena is only recent, with researchers developing protocols of predefined movement sequences. Thus, the task of the fitness coach interaction appears to be in ideal position to contribute to both Human Sciences (by contributing to the understanding of movement quality communication and synchronization) and Computer Sciences (by developing a virtual coach application), both leading to translational research.

2. RESEARCH APPROACH AND METHOD

2.1. Overview

The context of the researches presented in this chapter was an interdisciplinary project about the design of interactive virtual humans endowed with credible interactive skills (INGREDIBLE). The project being originally based on artistic protocol, we (the LIMSI team) proposed to develop our own approach based on sports tasks.

The choice of the fitness task has been driven by the attempt to define a task which naturally constrains the social, motor and cognitive phenomena involved. The advantage of the fitness task is that it fixes the motion sequence allowing to concentrate on the expressiveness and the timing of the interaction solely. These two aspects can interact: adjusted once timing can modulate the perceived expressivity of the motion sequence. However, in a first approach we artificially treat them separately in two research steps based on two different motion capture corpus. As with the rest of this PhD thesis, the underlying goal is twofold: contribute to the understanding of related social phenomena (here impression formation and interactional synchrony) as well as propose the design of an interactive virtual human application.

The following of the chapter is composed of three main parts. First, the coach expressivity is analyzed: the collected corpus is described and a perceptual study is presented. The perceptual study aimed at investigating what impressions (perceived movement qualities, personality and emotions) are formed when looking at the performed motion sequence from the coaches. In the original corpus, personality and emotions were self-reported by the coaches allowing us to study the accuracy of these impressions. This perceptual study is also a way to annotate with expressive labels our corpus in order to be able to synthesize stylistic motion sequences. The second step of our approach has been to study the synchronization patterns emerging when coaches perform the same motion sequence in a dyad. We present the collected motion capture corpus and perform a coordination analysis structured in the same way as in chapter 4: analysis of the mutual changes and then analysis of synchrony via cross lagged correlations. In both part, a particular interest will be given to individual differences and how they modulate these effects. In the coach expressivity analysis we focus on the Five Factor model of personality but we enlarge to affective alexithymia and three facets of empathy (personal distress, empathic concern and perspective taking) for the interpersonal analysis. The last and third party presents our design of a virtual interactive fitness coach based on these two analyses: the expressivity can be defined before the interaction (e.g., perform the motion sequence in a highly motivated way) and the online synchrony is adjusted via the management – thanks to the prediction – of the lag. The minimalist nature of the proposition aims at fitting both the objectives of an application driven development (to engage the user in a believable interaction) and an experimental driven development (to reproduce the reality in order to investigate it further in a controlled and systematic way). Lastly, we conclude this chapter and propose some perspectives.

2.2. Coach expressivity: hypotheses

The aim of this study is to study the extent to which spontaneous emotions and personality traits are perceived through full body movement qualities with non-expert observers in the context of a fitness coaching task. Knowing what drives social perceptions and whether they are accurate will provide us guidelines and labeled data for the design of a full body virtual interactive sport coach to provide a personalized and credible coaching experience. Because the focus is the individual expressivity, we investigated the FFM traits only (the five) as we have no reasons to hypothesize a link between individual differences in empathy, emotion regulation or interpersonal personality theory in non-interactive setups.

The originality of our approach resides in several points. First, the analysis is based on a corpus of objective measures for the motion capture data of non-acted expressivities: coaches (with their inter-individual differences in terms of personality) performed the same predefined movement sequence several times and under different contexts, eliciting different emotions. While movement variations might be very subtle (and less perceivable than the ones collected using acted protocols), they are spontaneous per se (i.e., not activated from an internal model of each emotion and personality trait). Second, the kinematic variations of the motion sequences are analyzed both as distal cues (computed movement qualities) and proximal percepts (perceived movement qualities) using the effort-shape characterization proposed by Laban (1950) and Dell (1977). This enables us to analyze their pairwise similarities (e.g., computed weight with perceived weight) called *perceptual representation* for the first time in non-expert

observers. We expect to have positive pairwise correlations between the kinematics-based computation of movement qualities and untrained observers perceived movement qualities. Finally, we assessed both self-reported and judged emotions and personality traits to have a complete understanding of how non-expert observers perceive the nonverbal behaviors performed by the coach. For both social phenomena, *ecological validity, cue utilization* and *achievement* are assessed. For the perception of emotions, we expect high self-reported and perceived arousals to be related to a high value of energy (weight) and impulsiveness (time). We also hypothesize that arousal will be the only dimension accurately evaluated by observers because several studies observed that this dimension is the most clearly related to bodily behaviors (Glowinski et al. 2011). Given inconsistent results from the literature and the novelty of our task, we cannot draw expectations for the valence dimension. For the perception of personality traits (according to the five-factor model of personality), we expect extraversion and neuroticism to be related to computed movement qualities (Riggio and Riggio 2002). Participants with high-level scores of extraversion should be higher on computed energy (weight) and impulsiveness (time) than participants with lower level scores of extraversion. Participants with a high level of neuroticism should be lower on computed smoothness (flow) and spatial extent (shape qualities) than participants with a lower level of neuroticism. Given the novelty of our task and the few available results regarding studies with kinematics only, no a priori specific hypothesis can be formed regarding perceived personality traits. Based on previous studies, we expect observers to be inaccurate in personality trait evaluations (Thoresen, Vuong, and Atkinson 2012).

2.3. Coach interaction: hypotheses

The aim of this study is to investigate the synchronization patterns emerging during the dyadic performance of a predefined fitness motion sequence. The context of the task is not inherently emotional which enable us to directly build on the hypotheses drawn on chapter 2 and 3 by adapting them to the collected individual differences in the corpus: three traits from the FFM – agreeableness, neuroticism, extraversion –, affective alexithymia and three empathic traits – personal distress, empathic concern and perspective taking –. Their associated hypotheses are summarized below:

- Agreeableness : greater quantity
- Extraversion : greater leadership
- Neuroticism: nothing (because no ego-threat in this setup)
- Affective alexithymia : weaker quality
- Personal distress : weaker quality
- Empathic concern : greater quantity
- Perspective taking : greater quantity, greater quality and greater leadership

One variance of the collected corpus is that dyad members performed the motion sequence under different instructions: back to back as a control group (they do not see each other), face to face without explicit instructions to coordinate and face to face with the explicit instruction that the pupil should follow the coach motions. The difference between the instructed and non-instructed condition enable to differentiate the spontaneous from the intentional aspect of synchronization. Our hypotheses are mostly based on spontaneous synchronization. An interrogation is to whether they still hold in an intentional context. Our hypothesis is that the nature of the associations between the individual differences and the synchronization patterns might not change but their magnitude might decrease: the intentional controlled interaction might erase the between subjects' differences spontaneously emerging.

3. COACH EXPRESSIVITY: INDIVIDUAL ANALYSIS

3.1. Corpus

The perceptual study presented in this section is based on a corpus of predefined movement sequences performed by coaches with different personalities under different emotional contexts in order to induce variability in the expressivities. The collection of this corpus is extensively described elsewhere (Focone et al. *in prep*). The following section summarizes aspects that are specifically relevant for the scope of this chapter.

3.1.1. Participants and Materials

Twenty French sport science students (mean age = 21.3, SD = 1.7, 11 females) participated in the study. Participants' movements were collected with a full body motion capture system. The marker setup was composed of 36 markers. The experiment room was equipped with 10 infrared cameras (S250e Optitrack system, frequency: 120 Hz, resolution: 832*832). Before arrival, each participant had to learn a simple movement sequence involving the whole body. In each condition of the protocol, the participant was asked to repeat the whole choreography three times (average length of the three repetitions of 1:30 minute). The general instruction was to perform the choreography in the *best possible way*.

3.1.2. Emotional contexts

Each participant performed the movement sequence under four different conditions to induce variability in terms of emotional experience. First, the protocol began with the control condition: performing the movement sequence without any context. The three other conditions –*positive*, *negative*, and *motivated*- were counterbalanced across participants. In the positive condition, the participant received a reward for his participation (food and electronic devices of 10€ value) and watched a 1:30 minute mash-up of funny videos as a distraction task. In the negative condition, the experimenter explained to the participant that the video of the performance would be streamed in real-time at a remote lecture hall in front of hundreds of students for pedagogical purposes. Finally, in the motivated condition, the participant was asked to imagine him/herself as a fitness trainer who had to motivate his/her audience.

3.1.3. Movement qualities computation

Movement data were processed using Matlab R2012b. Positions from nine segments were used: hip, chest, head, arm, forearm, hand, upper-leg, leg, and foot. Five movement qualities were computed for each segment to model the effort-shape domain proposed by Laban (Laban 1950): *impulsiveness* (time), *energy* (weight), *directness* (space), *smoothness* (flow) and *density* (shape qualities). They were averaged on the whole body to obtain one time series per movement sequence per movement quality. Equations to model these qualities are described in Table 35. Because our protocol predefines the movement trajectory, the directness index will only vary according to speed. Therefore, we do not consider it in the analyses.

Times series	Descriptive	Equation
Impulsiveness (Equation 1)	Time effort can be determined as the net acceleration accumulated at the body parts over time (Equation 1). Plot this result on a determined time give us 9 time series (i.e., one for each segment). $Vi(t)$ is the instantly velocity of the i-th member.	$\text{Impulsiveness}_{\mathbf{member}} = \sum_{\mathbf{i=2}}^{\mathbf{T}} \frac{\lvert \mathbf{V(t_i)} - \mathbf{V(t_{i-1})} \rvert}{\mathbf{t_i} - \mathbf{t_{i-1}}}$ $\mathbf{V(t_i)} = \sqrt{\mathbf{Vx_{ti}^2} + \mathbf{Vy_{ti}^2} + \mathbf{Vz_{ti}^2}}$
Energy (Equation 2)	Weight effort can be determined as energy at each instant (t) (Equation 2). Plot this result on a determined time give us 9 time series (i.e., one for each segment). mi_{member} is the approximation of the mass of the it-th member according to the Winter table (Winter 2004). $Vi(t)$ is the instantly velocity of the i-th member.	$\text{Energy}_{\mathbf{member}} = \frac{\mathbf{1}}{\mathbf{2}} \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{mi_{member}} * \mathbf{Vi(t)^2}$
Directness (Equation 3)	Space effort is computed as the inner product of chest and member (i.e., right hand, left hand, right foot, left foot) trajectories at every time instance (Equation 3). $\overrightarrow{V_{chest}} * \overrightarrow{V_{member}}$ Represent tangents to chest and members positions. Plot this result on a determined time gives us 4 time series (i.e., one for each hand and feet).	$\text{Directness}_{\mathbf{member}} = \overrightarrow{\mathbf{V_{chest}}} * \overrightarrow{\mathbf{V_{member}}}$ $= (\mathbf{V_{chest\,X}} \quad \mathbf{V_{chest\,y}} \quad \mathbf{V_{chest\,z}}) * \begin{pmatrix} \mathbf{V_{member\,X}} \\ \mathbf{V_{member\,Y}} \\ \mathbf{V_{member\,Z}} \end{pmatrix}$
Smoothness (Equation 4)	Flow effort is determined as 3D curvature for each segment for each time. The curvature is a rapport between velocity and acceleration (equation 4). Plot this result on a determined time give us 9 time series (i.e., one for each segment). v_{xi} and a_{xi} indicate the first and second derivatives of x trajectory at frame i, respectively.	$\text{Smoothness}_{\mathbf{member}} = \frac{\sqrt{(\mathbf{v_{xi}} * \mathbf{a_{yi}} - \mathbf{v_{yi}} * \mathbf{a_{xi}})^2 + (\mathbf{v_{zi}} * \mathbf{a_{xi}} - \mathbf{v_{xi}} * \mathbf{a_{zi}})^2 + (\mathbf{v_{yi}} * \mathbf{a_{zi}} - \mathbf{v_{zi}} * \mathbf{a_{yi}})^2}}{(\mathbf{v_{xi^2}} + \mathbf{v_{yi^2}} + \mathbf{v_{zi^2}})^{\frac{3}{2}}}$
Density Index (Equation 6)	Shape Qualities describe the way the body is changing toward space. The index which can convey shape quality is the density index. This calculation is associated to the position of the segment according to the center of mass (Equation 5) at each time. Plot this result on a determined time give us one time series (i.e., one for the entire body). Dxi, dyi, dzi are distances between mass center coordinate (x_c, y_c, z_c) and the i-th member coordinate (x_i, y_i, z_i)	$\text{Density Index} = \frac{3}{4} * \boldsymbol{\pi} * \boldsymbol{DI_x} * \boldsymbol{DI_y} * \boldsymbol{DI_z}$ $\boldsymbol{DIx} = \frac{1}{n} \sum_{i=1}^{n} \boldsymbol{dxi} \quad \boldsymbol{DIy} = \frac{1}{n} \sum_{i=1}^{n} \boldsymbol{dyi} \quad \boldsymbol{DIz} = \frac{1}{n} \sum_{i=1}^{n} \boldsymbol{dzi}$ $\boldsymbol{dxi} = \sqrt{(x_i - x_c)^2} \quad \boldsymbol{dyi} = \sqrt{(y_i - y_c)^2} \quad \boldsymbol{dzi} = \sqrt{(z_i - z_c)^2}$

Table 35: Movement qualities computation Adapted from (Piana & al 2013; Kapadia et al 2013; Samadani & al 2013; Chen & al 2011).

3.1.4. Emotion and Personality Assessment

Experienced emotions and personality traits were assessed by self-reporting. Self-reported emotion states were assessed with the differential emotional scale (Ouss et al. 1990). While most of the labels were not used by participants (results totally left anchored on the Likert scales), two labels showed good variability across participants and conditions: *enjoyment* and *surprise*. In a dimensional view of emotions, enjoyment represents the valence dimension (i.e., positive) and surprise is associated with the activation dimension (Alvarado 1997). Personality traits were considered regarding the five-factor model (Costa and McCrae 1992), which characterizes an individual's personality across five broad traits, namely, extraversion, agreeableness, conscientiousness, neuroticism, and openness (John, Donahue, and Kentle 1991). The French version of the Big Five Inventory was used (Plaisant, Courtois, Réveillère, Mendelsohn, & John, 2010).

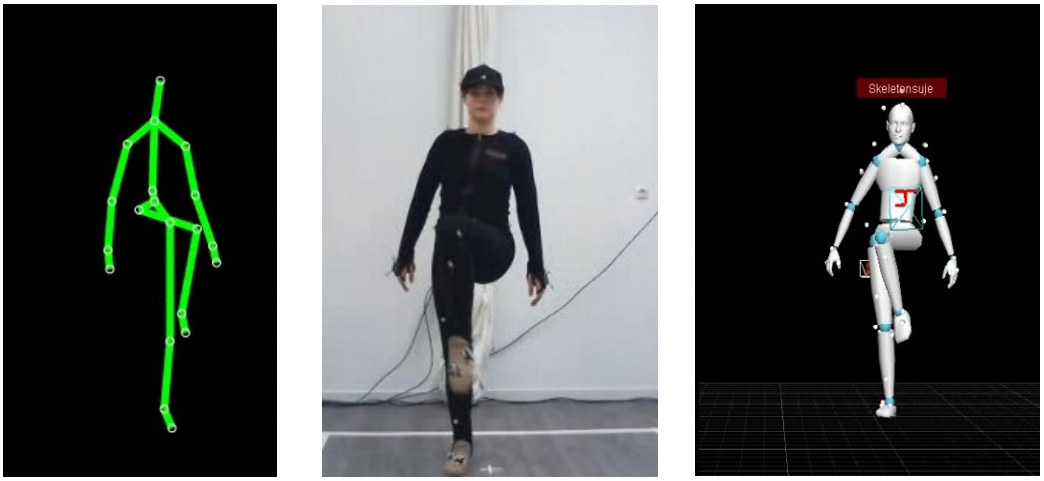


Figure 63: Motion captures via a kinect, a webcam and a motion capture system

3.2. Perceptual analysis methodology

3.2.1. Analysis framework

To structure the analysis of the perception process composed of the expression, transmission and perception of social cues, we follow the paradigm proposed by Scherer (1978), (Scherer 2013). As depicted in Figure 64, the framework describes four elements: distal environmental criterion (e.g., personality traits), distal cues (e.g., movement speed), proximal percepts (e.g., perceived movement speed) and evaluated criterion (e.g., perceived personality traits).

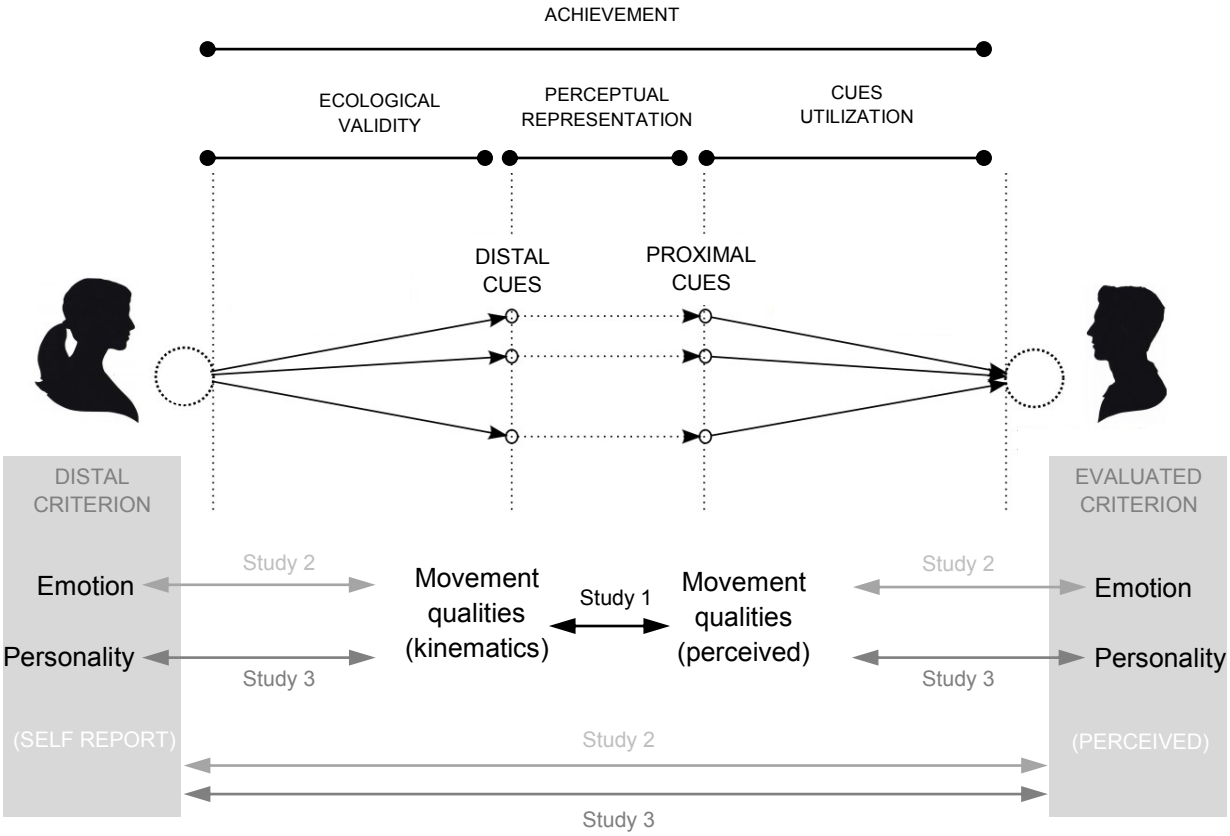


Figure 64: Analysis framework inspired by (A. Vinciarelli and Mohammadi 2014)

These four elements are studied via four analyses: *ecological validity, cue utilization*, *achievement* and *perceptual representation*. In this study, we organize them in three studies. First, the *perceptual representation* of movement qualities is analyzed. Validating the assumed inherent link between kinematics and the perceptual aspects of these qualities is a key point to understanding the decoding process. Second, *ecological validity, cue utilization* and *achievement* are studied for the communication (recognition-identification) of emotional states. Finally, *ecological validity, cue utilization* and *achievement* are studied for the communication (recognition-identification) of personality traits.

3.2.2. Participants

Thirty-two French participants were involved in this perceptual study (mean age = 32.6, SD = 15.7, 15 females). The perceptual test was made available online. Participants were contacted by email with only information on the approximate survey duration and the conditions to undertake the survey: placed in a quiet place with good Internet access and seated at a comfortable distance from the screen. Participants were not paid.

3.2.3. Materials

The selection of one movement sequence in each condition from fourteen coaches of the corpus (n=20) was selected to reduce the duration of the survey to ninety minutes. The fourteen coaches were chosen randomly. This resulted in 56 movement sequences of 30 seconds each. To control the effect of the physical appearance of participants in the corpus (gender, size, weight, etc.)(Atkinson et al. 2004), a video was made of a 3D virtual mannequin playing the motion capture data. Each video was reframed to control the mannequin size. Each video was preceded by a white fixation cross and followed by the display of one sentence asking the participant to complete the questionnaire. Video key frames are presented in Figure 65. Self-reported personalities (five-factor dimensions from the BFI-fr; Plaisant et al., 2010), self-reported affective experiences (enjoyment and surprise scales from the DES; Ouss et al., 1990) and computed movement qualities are known for each movement sequence.

3.2.4. Procedure

The first part of the instruction section described the general aim of the study as "*the study of the movement expressivity of a virtual coach*". It also recalled the structure of the survey. The second part presented the instructions regarding the good conditions that a participant should be in before continuing. It also explained the nature of the videos to be evaluated: every video is a different movement sequence but with the same appearance (a 3D virtual manikin). Nothing about the identities (body and face) or the conditions of the capture session was provided to the participant. The third part asked the participant for socio-demographic information (sex, age, practiced sport and level of expertise, contact). The following three pages provided detailed definitions regarding the dimensions to be evaluated for each video. These dimensions were grouped under three labels: movement qualities, emotions and personalities. For each dimension, a set of synonyms and a left and right anchor were provided to constitute a semantic differential scale. When possible, the labels were taken from the literature. At the end of each definition, participants were asked to report the clarity of the scale on a five-item Likert scale. Table 36 shows the dimensions with their associated left and right anchors. Each dimension is evaluated on a 10-item Likert scale.

* *Fill out the questionnaire. Click on next when you are done. Thank you.*

Figure 65: Video stimulus presented to the participant for each movement sequence

Movement qualities	Left anchor[a]	Right anchor[b]	Average inter-rater correlations (r)	Spearman-Brown Coef. (R_{sb})	Cronbach alpha (α)
Smoothness	Abrupt	Smooth	0.18	0.89	0.86
Directness	Indirect	Direct	0.09	0.66	0.68
Energy	Limp	Energetic	0.53	0.96	0.97
Impulsivity	Restrained	Impulsive	0.46	0.95	0.96
Spatial extension	Restricted	Vast	0.41	0.95	0.95
Emotion	Left anchor[a]	Right anchor[b]			
Valence	Negative emotion	Positive emotion	0.39	0.95	0.95
Intensity	Low intensity	Strong intensity	0.33	0.95	0.93
Dominance	Subdued	Dominant	0.37	0.93	0.94
Motivation	Without motivation	Strongly motivated	0.40	0.95	0.95
Stress	Relaxed	Stressed	0.09	0.75	0.76
Personality	Left anchor[a]	Right anchor[b]			
Extraversion	Introverted	Extroverted	0.40	0.93	0.95
Openness	Humdrum	Adventurous	0.38	0.95	0.94
Neuroticism	Neurotic	Stable emotionally	0.17	0.87	0.84
Conscientiousness	Careless	Conscientious	0.08	0.65	0.67
Agreeableness	Disagreeable	Warm	0.31	0.93	0.92

[a] Score = 1

[b] Score = 10

= not acceptable reliability

Table 36: Evaluated dimensions with their left/right anchors and their raters' reliability indicators

Before the evaluation part, the participants viewed and rated three training trials. These trials were movement sequences that were not part of the set of sequences used in the perceptual study. All of the definitions were recapped at the bottom of the page to enable the participant to read them again if needed. For the evaluation part, the participant viewed and rated the 56 videos. The video order was randomized across participants.

3.2.5. Item clarity and Rater reliability

All of the dimensions were rated by participants as having very clear meanings, but the less clear dimension was Dominance (mean clarity = 4.25, on a five-item Likert scale). Looking at the averaged pairwise inter-rater correlations averaged across all 16 dimensions, two raters were below the threshold of 0.20 (very low agreement with other raters). These two raters were removed from the study. We performed an outlier analysis on average scores and a standard deviation of the scores per participant on each of the 16 scales (Hoaglin, Iglewicz, and Tukey 1986). Three raters were removed based on this analysis. A second outlier analysis on standard deviation across the 16 dimensions for each movement sequence aimed at looking for participant ratings systematically (when not taking seriously the survey, a standard deviation of zero means rating every scale with the same response). This analysis revealed no supplementary outliers. Three different indicators of the raters' reliability were computed for the 30 remaining raters on each dimension (Table 36). The average inter-rater correlations show the amount of agreement, and the Spearman-Brown coefficient shows the effective reliability (Rosenthal 2008). We also provide Cronbach's alphas (often reported as an alternative reliability indicator (M. M. Gross, Crane, and Fredrickson 2010)). Three dimensions –Directness, Stress, Conscientiousness- showed very poor agreement ($r<0.1$) and reliabilities ($R_{sb}<0.8$ and $\alpha<0.8$) and were removed from the analysis. For the 12 remaining scales, the raters' scores were averaged for each video for the analysis.

3.2.6. Correlation bias and General impression: selecting and transforming variables

A first look at bivariate correlations between evaluated dimensions revealed moderate to strong positive correlations between all dimensions ($r>0.6$) and all were highly significant ($p<0.01$). This high common variance was confirmed by a principal component analysis, suggesting a one-component structure accounting for 88.2% of the total variance. The existence of sizeable pairwise correlations between rated items is a common aspect of judgment studies. This phenomenon has been coined the "*Halo effect*" (Thorndike 1920) or "Exaggerated emotional coherence" (Morewedge and Kahneman 2010), that is, the tendency to think of a person or an object in a generalized impression. This exaggerated coherence is considered to be caused by raters' assumptions concerning the co-occurrence of rated items (Podsakoff et al. 2003). Not considering this inherent multicollinearity in judgment studies can lead to methodological issues and ambiguous results (Kraha et al. 2012).

Before analyzing this general impression as a social perception characteristic of our task, one aspect should be controlled. This source of multicollinearity could result from a method bias: the duration of the survey and the number of items to be evaluated at the same time tend to increase the risk of correlation bias (Cooper 1981). One way to clarify this issue is to compare the Halo effect in two judgment conditions, the second being hypothetically less subject to associative processes (Johnson 1963). We designed three shorter versions of the test, each one with different dimensions to be evaluated (one with the five movement quality dimensions, one with the five emotional dimensions and one with five personality traits dimensions). Each test had only 20 movement sequences per rater. For these tests, the question orders were also randomized at each movement sequence. The duration was considerably reduced (24 minutes on average compared to 96 minutes on average for the long version). A multitrait-multimethod matrix (MTMM) (Campbell and Fiske 1959) was computed to compare the two methods (full matrix in Appendix B). Table 37 provides item reliabilities and inter-method correlations to assess convergent validity. Only the

neuroticism scale showed no convergent validity and a very poor reliability in the short form of the test. This scale was removed from the study.

The 11 remaining scales can be considered free from method bias and subject to a large Halo effect. The existence of this strong general impression is not surprising given our task. Raters were asked to give their "*first spontaneous impression*" regarding very subtly different movement sequences without any contextual information. Given this high ambiguity, they relied on prior knowledge/beliefs and favored fast associative judgments based on the few salient elements. To disentangle the general impression from the specific component of the evaluation, we use a procedure similar to Landy et al. (1980). First, we extract the general impression (G) over the remaining 11 scales with an exploratory factorial analysis (EFA with the maximum likelihood estimation method). This method is more appropriate than a principal component analysis because its objective is to reproduce the inter-correlations of a set of indicators, recognizing a part of a unique variance for each (Brown 2006). The second step is to partial out the general component from each variable by regressing them on G. Using the residuals as unique over the shared contribution of the predictors is often performed in cases of correlated variables (Graham 2003), (Engell, Haxby, and Todorov 2007). The extracted residuals from these regressions form the specific part of the evaluation. Correlations between observed and specific components for each scale are presented in Table 37. For the rest of the analysis, we keep the specific components that correlate significantly with their observed part. They still contain a meaningful part of the observed variance once the general component variance is removed.

Dimensions		Nb of raters		Reliability (Rsb)		Inter-methods correlations	Observed / Residuals correlations
		Long	Short	Long	Short		
Movement qualities	Smoothness	27	10	0.89	0.81	.828**	.644**
	Energy	27	10	0.96	0.86	.949**	0.233
	Impulsivity	27	10	0.95	0.86	.928**	0.242
	Spatial extension	27	10	0.95	0.90	.901**	.486**
Emotion	Valence	27	10	0.95	0.87	.805**	0.260
	Intensity	27	10	0.95	0.91	.883**	.280*
	Dominance	27	10	0.93	0.88	.736**	.267*
	Motivation	27	10	0.95	0.83	.869**	0.254
Personality	Extraversion	27	12	0.93	0.92	.888**	0.198
	Openness	27	12	0.95	0.88	.844**	0.113
	Neuroticism	27	12	0.87	-0.16	.243	-
	Agreeableness	27	12	0.93	0.84	.830**	.363**

* for p<0.05
** for p<0.01

Table 37: Rated dimension characteristics

This procedure provided a reduced number of variables: general impression (G), perceived smoothness (P-smoothness), perceived spatial extent (P-spatial extent), perceived intensity (P-intensity), perceived dominance (P-dominance) and perceived agreeableness (P-agreeableness). In addition to a considerably reduced multicollinearity in our data, the data provided a more representative picture of the discriminative power of the raters. This general impression (G, composed mainly of impulsivity, energy, valence, motivation, extraversion and openness) seems coherent with the "*overall expressive level of people's interpersonal behavior*", working as an expressivity halo similar to Bernieri et al. (1996). Because they include movement qualities such as emotion dimensions and personality traits, the general impression G will be considered in the three studies.

3.3. Study 1: Perceptual representation of movement qualities

In this first study, we analyze the relations between movement qualities, computed or observed, within our corpus. Our aim is twofold: to understand how movement qualities are related to each other (e.g., is energy independent of smoothness?) and to assess the associations between untrained observers' ratings and quantified movement qualities.

3.3.1. Computed movement qualities

For each movement sequence, five movement qualities were computed to model the effort-shape domain (Dell, 1977) proposed by Laban as described previously: energy, impulsivity, directness, spatial extent and smoothness. Table 38 shows pairwise correlations between computed movement qualities for the 56 movement sequences from our corpus.

	C-energy	C-impulsivity	C-spatial extent	C-smoothness
C-energy	1	0.89**	0.36**	0.50**
C-impulsivity		1	0.21	0.42**
C-spatial extent			1	0.37**
C-smoothness				1

* for p<0.05
** for p<0.01

Table 38: Pearson correlations between computed movement qualities (n=56)

Computed energy and impulsivity are strongly and positively correlated (r=0.89, p=0.001). Computed smoothness is negatively and moderately correlated to all dimensions (r<-0.35, p<0.01). Computed spatial extent is moderately and positively correlated to computed energy (r=0.360, p=0.006). These results show a significant amount of shared variance across our movement qualities, with energy and impulsivity being very close dimensions.

3.3.2. Perceived movement qualities

On the perceptual side, three movement qualities are available: the general impression (mainly composed of energy and impulsivity), perceived smoothness and perceived spatial extent. Table 39 shows pairwise correlations between the perceived movement qualities for the 56 movement sequences of our corpus.

	G	P-smoothness	P-spatial extent
G	1	0.00	0.00
P-smoothness		1	0.09
P-spatial extent			1

* for p<0.05
** for p<0.01

Table 39: Pearson correlations between perceived movement qualities

The general impression does not correlate with perceived smoothness and perceived spatial extent per se (shared variance removed). Perceived smoothness and spatial extent are orthogonal as well (r=0.093, p=0.500). For our corpus, the observers' perceptual realm is, therefore, composed of three independent variables.

3.3.3. Perceptual representation

Perceived movement qualities are not necessarily highly correlated to compute movement qualities means. For example, perceived energy could be more highly correlated to the computed energy peaks in time (which are more

salient) than the computed energy mean. To analyze the relations between perceived movement qualities and a larger spectrum of movement qualities computations, we computed eight values around the mean representing intermediates between the minimum (=10%), mean (50% in figure 3) and maximum (=90%). Considering a time series, the mean (50% in figure 3) is a value where the area under and above the curve is equal (each represents 50% of the total area under the curve). The eight values computed are the ordinates, where the area under the curve is increased or decreased by 10%. In Figure 66, each graph shows pairwise correlations between the three perceived movement qualities and the nine computed variables of the treated quality.

Strong positive correlations were found between general impression G and computed energy (r=0.821, p=0.000 for 50%) and impulsivity (r=0.935, p=0.000 for 50%), regardless of the mean variations. G was positively and moderately correlated with computed smoothness (p=0.615, p=0.000 for 40%). Because the factor G is mainly composed of perceived impulsivity variance, these results show a high convergent validity between G and the computed impulsivity mean: the highest pairwise correlation and the same pattern of correlations with other computed qualities. There was a positive weak correlation between the perceived spatial extent and computed energy (r=0.274, p=0.041 for 50%), weak positive correlations between the perceived spatial extent and computed spatial extent (r=0.343, p=0.010 for 50%) and a positive and moderate correlation between the perceived spatial extent and low values of computed smoothness (r=0.496, p=0.000 for 10%).

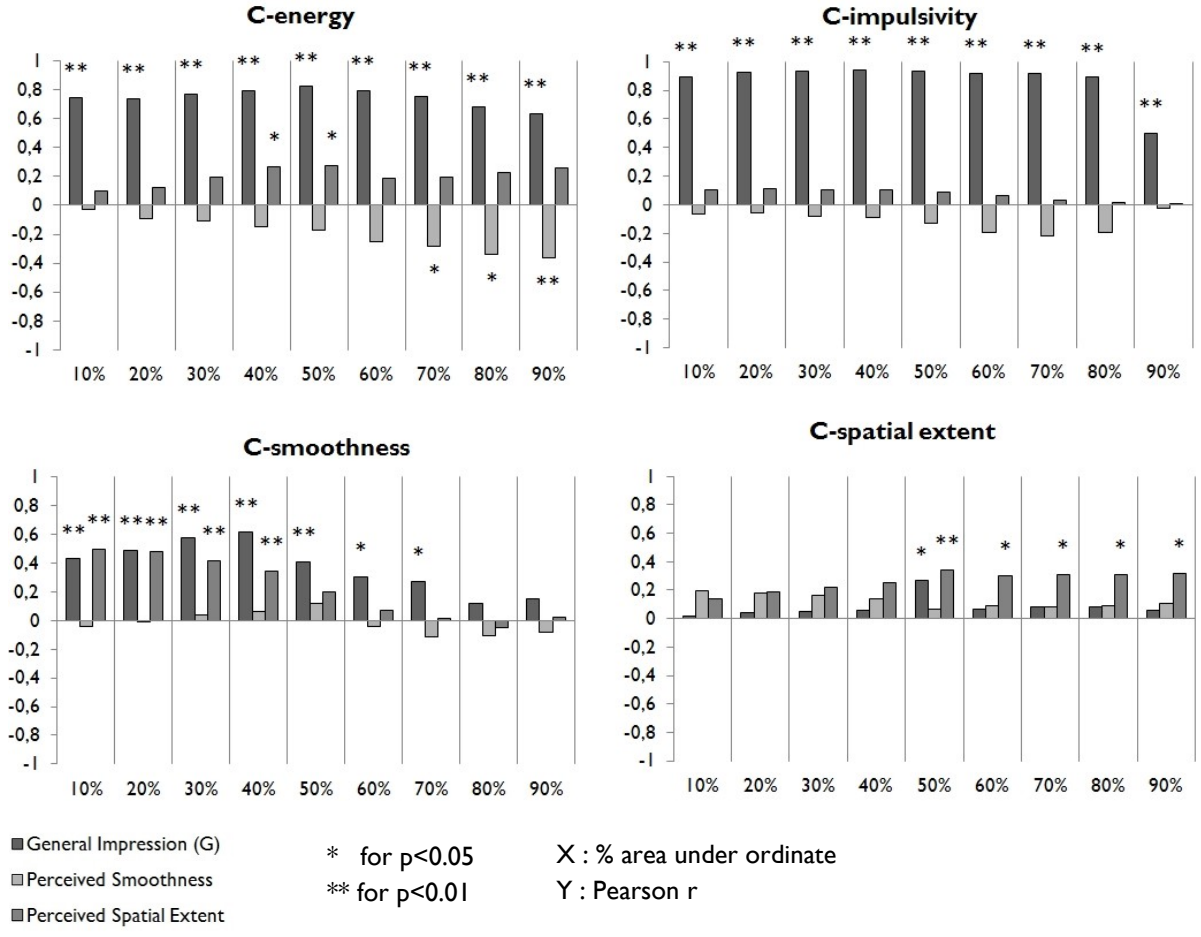


Figure 66: Correlations between computed and perceived movement qualities

The first two results regarding the perceived spatial extent show partial convergence between the computed and perceived spatial extents. The negative correlation between the perceived spatial extent and low values of computed smoothness is less interpretable but does not impair the convergent validity because the computed spatial extent (for 50%) correlates positively with computed smoothness (r=0.323, p=0.015 for 10%). Perceived smoothness was

negatively correlated with high values of computed energy only (r=-0.362, p=0.006 for 90%). Thus, perceived smoothness shows no convergent validity with computed smoothness. The perceptive variable was more associated with peaks of energy within the time series.

This first study shows that observers were highly accurate in evaluating kinematic impulsivity. This perceived impulsivity seems to be the basis for the general impression G. Perceived spatial extent showed partial convergent validity and perceived smoothness with no convergence at all. Overall, untrained observers were only heterogeneously accurate, contrasting with previous studies showing good agreement between certified movement analysts and computed qualities. For the following two studies, we will keep both movement qualities and evaluations (perceived and computed) in the analysis.

3.4. Study 2: Emotion Analysis

In this second study, we analyzed the perception process of emotions through full body movement qualities, computed or observed, within our corpus. Our aim is twofold: to understand how movement qualities are related to self-reported and perceived emotions and to assess the accuracy of emotional perception.

3.4.1. Ecological validity and Cue utilization in emotion perception

For each movement quality (computed and perceived) and each emotion, we tested the extent to which the movement qualities correlated with the induced emotion (ecological validity). We also tested the extent to which movement qualities correlated with perceived emotions (cue utilization). Table 40 presents the ecological validity and cue utilization for emotions (self-reported and perceived).

Self-reported emotions show that computed and perceived cues correlate. Participants' self-reports of enjoyment were positively correlated to the computed spatial extent and perceived general impression and were negatively correlated to the perceived spatial extent. Self-reported surprise was positively correlated with all cues but not with perceived smoothness. While felt surprise seems clearly related to the general impression and impulsivity (which share some variance with all computed movement qualities), the pattern for enjoyment is less clear: movements were found to be more expanded kinematically but perceived as being less expanded and more impulsive.

In terms of perceived emotion, the general impression G is mainly composed of valence. Observers' perceptions of valence were most strongly correlated with computed energy and impulsiveness and were moderately correlated with computed spatial extent and computed smoothness. Perceived intensity was not correlated with any computed movement qualities. It was positively correlated to spatial extent and negatively correlated to perceived smoothness. Observers' perceptions of dominance were moderately and negatively correlated with computed smoothness and perceived spatial extent. Overall, these results suggest different patterns in cue utilization for all three perceived emotions: perceived valence is mainly driven by impulsivity (computed and perceived as G is an accurate perception of impulsivity). Movements perceived as being more intense were perceived as being more expanded and jerkier without kinematic correlates. Finally, perceived dominance was kinematically jerkier but perceived as being less expanded.

Both in ecological validity and cue utilization, significant correlations exist between emotions (self-reported or perceived) and computed and perceived movement qualities. Only perceived intensity showed no computed movement qualities correlates. This means that sufficient information exists for the observer to form accurate perceptions of felt emotions: experienced emotions are kinematically encoded (i.e., embodied) and are correlated

with perceived movement qualities, and these same computed and perceived cues are correlated with perceived emotions.

Ecological validity		Perceptual cues	Cue utilization		
S-enjoyment	S-surprise		G	P-intensity	P-dominance
		Distal cues			
0.13	0.43**	C-energy	0.82**	0.23	-0.16
0.24	0.44**	C-impulsiveness	0.94**	0.15	-0.01
0.36*	0.34*	C-spatial extent	0.27*	-0.07	-0.19
-0.02	0.40**	C-smoothness	0.41**	0.12	-0.43**
		Proximal percepts			
0.28*	0.48**	G	1.00	0.00	0.00
-0.36*	0.27*	P-spatial extent	0.00	0.37**	-0.48**
-0.07	0.09	P-smoothness	0.00	-0.27*	-0.23

* for p<0.05
** for p<0.01

Table 40: Ecological validity and cue utilization for emotions

3.4.2. Achievement between self-reported and perceived emotions

For each emotion, we tested the extent to which the perceived emotions correlated with the participant's actual emotion (achievement) to find out if observers were accurate in their ratings. Table 41 presents the achievement for emotions (self-reported and perceived).

Perceived valence (general impression G) was positively correlated with both self-reported enjoyment and surprise, more strongly with the latest. Perceived intensity showed no significant correlations. Perceived dominance was positively correlated to self-reported enjoyment and negatively correlated to self-reported dominance. These results demonstrate partial accuracy in observers' perceptions. Accuracy was weak for valence (represented by S-enjoyment and G, respectively) and was nonexistent for arousal (represented by S-surprise and P-intensity, respectively). The association between general impression and felt surprise demonstrates that observers were not able to differentiate experienced enjoyment and surprise and that they rated them as being equally expressive. Dominance accuracy is difficult to assess because it is not self-reported directly. However, in the literature, enjoyment is considered a dominant emotion, and surprise is a non-dominant emotion (Russell and Mehrabian 1977), (Dael, Goudbeek, and Scherer 2013). Following this classification, perceived dominance showed partial accuracy.

		Evaluated criterion		
		G	P-intensity	P-Dominance
Distal criterion	S-enjoyment	0.28*	-0.20	0.32*
	S-surprise	0.48**	0.17	-0.33*

* for p<0.05
** for p<0.01

Table 41: Achievement for emotions

3.5. Study 3: Personality Analysis

In the third study, we analyzed the perception process of personality through full body movement qualities, computed or observed, within our corpus. The aim is twofold: to understand how movement qualities are related to self-reported and perceived personality traits and to assess the accuracy of personality perceptions.

3.5.1. Ecological validity and Cue utilization in personality perception

For each movement quality (computed and perceived) and each personality trait, we tested the extent to which the movement qualities correlated with the coach's actual personality (ecological validity) and the extent to which movement qualities correlated with perceived personality (cue utilization). Table 42 presents the ecological validity and cue utilization for personality (self-reported and perceived).

Self-reported personality traits showed that computed and perceived cues correlate. Coaches' self-reports of extraversion were positively correlated to the computed spatial extent. Self-reported openness was negatively correlated with computed energy and perceived spatial extent. Self-reported neuroticism was positively correlated with computed energy, general impression and perceived smoothness. Participants' agreeableness scores were negatively correlated with computed spatial extent and perceived spatial extent. Finally, self-reported consciousness was only positively correlated to perceived smoothness. These results show that movement qualities (perceived or computed) convey some information regarding individual personality traits: as in the literature, individual highs in extraversion make movement more expanded, but the other traits have their associations.

In terms of perceived personality traits, the general impression G is mainly composed of extraversion and openness. Observers' perceptions of extraversion and openness (within G) were most strongly correlated with computed energy and impulsiveness and moderately correlated with computed spatial extent and computed smoothness. Perceived agreeableness was positively correlated with computed spatial extent and perceived smoothness.

Both in ecological validity and cue utilization, significant correlations exist between personality traits (self-reported or perceived) and computed and perceived movement qualities. Only self-reported conscientiousness showed no computed movement quality correlations. This suggests that sufficient information exists for the observer to form accurate perceptions of self-reported personality traits: personality characteristics are kinematically encoded and are correlated with perceived movement qualities. These same computed and perceived cues are correlated with perceived personality traits.

Ecological validity					Perceptual cues	Cues utilization	
S-extraversion	*S-openness*	*S-neuroticism*	*S-agreeableness*	*S-conscientiousness*		*G*	*P-agreeableness*
					Distal cues		
-0.10	-0.29*	0.27*	-0.14	-0.22	C-energy	0.82**	-0.13
-0.03	-0.26	0.26	0.00	-0.09	C-impulsiveness	0.94**	-0.19
0.55**	-0.01	0.16	-0.44**	0.02	C-spatial extent	0.27*	0.28*
0.25	-0.02	0.22	-0.10	0.15	C-smoothness	0.41**	0.25
					Proximal percepts		
0.04	-0.15	0.40**	-0.00	-0.05	G	1.00	0
0.06	-0.39**	-0.06	-0.29*	-0.13	P-spatial extent	0.00	0.01
0.23	0.04	0.30*	0.10	0.42**	P-smoothness	0.00	0.57**

* for p<0.05
** for p<0.01

Table 42: Ecological validity and cue utilization for personality traits

3.5.2. Achievement between self-reported and perceived personality

For each personality trait, we tested the extent to which the observers' perception of personality traits correlated with the coaches' actual personality traits (achievement). Table 43 presents the achievement for these traits (self-reported and perceived).

Perceived extraversion and openness (within the general impression G) were positively correlated with self-reported neuroticism. Perceived agreeableness showed positive correlations with self-reported extraversion and openness. These results demonstrate no accuracy in observers' perceptions of personality traits. Instead, their perceptions were associated with other personality traits, indicating wrong attributions. The wrong evaluation of self-reported neuroticism was probably caused by the mediating variable computed energy: aroused by the protocol, more neurotic people made more energetic movements than perceived by an extrovert and open personality person.

		Evaluated criterion	
		G	P-agreeableness
Distal criterion	S-extraversion	0.04	0.29*
	S-openness	-0.15	0.27*
	S-neuroticism	0.40**	0.09
	S-agreeableness	-0.00	0.10
	S-conscientiousness	-0.05	0.22

* for p<0.05
** for p<0.01

Table 43: Achievement for personality traits

3.6. Discussion

The three studies presented in this section aimed at contributing to our understanding of emotions and personality trait perception based only on kinematic information provided by full-body movements. The specific context of our task is a fitness coach who continuously guides non-expert users through the movements to be performed. Thus, task movement was a predefined sequence performed in various emotional contexts and varied according to the coach's personality. Kinematic patterns of movement were analyzed in terms of movement qualities according to the effort-shape notation (Dell 1977) proposed by Laban (1950). Thirty-two participants were asked to rate movements in terms of conveyed emotion dimensions, personality traits (five-factor model of personality) and perceived movement qualities (effort-shape) for fifty-six fitness movement sequences from our corpus.

Before conducting the three studies, the exploration of collected data from raters revealed that high inter-correlations were present between the evaluated dimensions (movement qualities, emotions and personality traits). Approximately 88% of the total variance could be explained by a unique component mainly composed of perceived impulsivity, energy, valence, motivation, extraversion and openness. Although it is not often reported in the literature, this general impression is coherent with the interpersonal halo reported by Bernieri et al. (1996). These authors summarize this general impression as "*what is expressive is good*". Our methodological approach consisted of computing this general impression to form a new variable and to extract the specific variance of other variables to avoid multicollinearity. In the design of a virtual coach, this general impression would be the first variable to model because it conveys most of the positive attributes. The following studies that we described decomposed the analysis in three steps: the first study considered the perceptual representation of computed movement qualities; the second study analyzed how emotions are perceived through the kinematic modality; and the third study analyzed how personality traits are perceived through the kinematic modality.

In study 1, the associations between computed and perceived movement qualities (called perceptual representation) were analyzed. The only previous work that compared manual annotation by a certified movement annotator and the computed movement qualities revealed a high agreement across the effort-shape domain for acted arm movements (Samadani et al. 2013). In our work, with non-expert observers and spontaneous full body movement in contrast to our hypothesis, we found only partial convergence validity between movement qualities computed from kinematic variables and perceived movement qualities. The general impression G was accurately driven by movement impulsivity (amount of acceleration), but perceived spatial extent was only partially related to computed spatial extent and perceived smoothness was not related to computed smoothness. We also analyzed the relations between perceived movement qualities and a larger spectrum of computations of the effort-shape dimensions: this analysis revealed that perceived smoothness was correlated with higher values of energy. We can draw two conclusions from these results. First, the general impression conveying most of the positive attributes is accurate: in the context of a virtual coach, varying movement impulsiveness is the first parameter to explore. Second, for non-expert observers, how the kinematics is perceived is not necessarily what kinematics is: more study is required to evaluate what drives perceived smoothness and spatial extent. An alternative method would be to automatically explore possible computations of perceived movement qualities (Kikhia et al. 2014).

In study 2, the associations between movement qualities (perceived and computed) and emotions (perceived and self-reported) were analyzed. Based on previous works (Glowinski et al. 2011), we hypothesized that high self-reported and perceived arousals would be related to high values of energy (weight) and impulsiveness (time). We also hypothesized that arousal would be the only dimension accurately evaluated by observers. Our results partially confirm our expectations: felt surprise (considered as representing the arousal dimension) and enjoyment (considered as representing the valence dimension) were positively correlated to the general impression, revealing no accuracy and moderate accuracy, respectively (M. M. Gross, Crane, and Fredrickson 2010). The association between general impression and felt surprise demonstrates that observers were not able to differentiate experienced enjoyment and surprise and that they rated them as being equally expressive. While perceived intensity was not accurate, perceived dominance showed partial accuracy with a positive correlation with self-reported enjoyment and a negative correlation with self-reported surprise (Russell and Mehrabian, 1977), (Dael et al., 2013). From this study, we can conclude that in our fitness task, arousal and valence are dimensions that are perceptually merged within the general impression: a more impulsive coach will convey more positive and activated affects. Dominance is an interesting dimension, which is associated with an impression of control over an event. Kinematically, motions were jerkier and were perceived as being less expanded, which corresponds with contracted and controlled movements.

In study 3, the associations between movement qualities (perceived and computed) and personality traits according to the five-factor model (perceived and self-reported) were analyzed. Based on previous works (Riggio and Riggio 2002), we hypothesized that coaches who rate high on extraversion should be higher for computed energy (weight) and impulsiveness (time) than participants with lower level scores of extraversion, and coaches with a high level of neuroticism should be lower on computed smoothness (flow) and spatial extent (shape qualities) than participants with a lower level of neuroticism. We also expected no accuracy in personality trait perception (Thoresen, Vuong, and Atkinson 2012). Our results confirm our hypothesis partially: as in the vast literature on personality, self-reported extraversion was observed to be related to computed spatial extent (La France, Heisel, and Beatty 2004). Self-reported neuroticism showed different associations from our expectations: more neurotic coaches had more energetic movements and were perceived as more impulsive and smoother. We interpret this discrepancy from the literature as a result of our protocol: the act of performing a fitness movement in a motion capture suit in front of dozens of cameras can be considered arousing per se. Neurotic individuals might have been more sensible to this arousing context, leading to more energy expenditure. In terms of perceived personality traits, extraversion and openness were embedded in the general impression G and, therefore, were associated with impulsivity. This association seems to be consistent with a description of extrovert people as energetic individuals (Costa and McCrae 1992). However, in our task, it was misleading: extrovert coaches performed more expanded movements, not more

impulsive movements. Perceived agreeableness was positively correlated with computed spatial extent and perceived smoothness. Although we did not form an hypothesis regarding this dimension, this result is interesting because agreeableness has been observed to be related to individuals engaging in smooth interaction with others (Graziano et al. 2007). From this last set of results, we can draw two conclusions. First, information regarding personality traits is conveyed by coaches' kinematics computed as movement qualities, but observers are not able to accurately identify them: more information might be needed to reduce the ambiguity of the signals. Second, two personality traits might be advantageously expressed by a virtual coach: extraversion embedded in the general impression driven by movement impulsivity and agreeableness, which is strongly associated with perceived smoothness. However, additional analyses are required to identify what kinematic patterns drive this perceived smoothness.

3.7. Future directions

The nature of our perceptual protocol, where observers were passively watching movement sequences, is a limitation. As future users will actively perform the movement following the virtual coach, their perception of emotion and personality traits might be different. An interesting question in our future experimental setup would be to reproduce the perceptual evaluation of this study after performing an interactive session with the virtual coach.

The presentation of movement sequences via a neutralized 3D manikin also raises several questions. In our analyses, although accuracy is low for most dimensions, we noted that social information was conveyed through movement qualities and social perception was related to movement qualities. This means that observers perceived information but were not able to disambiguate it probably as a consequence of the impoverished stimuli. Additional cues such as physical appearance and facial expressions would probably interact with the perception of emotion and personality traits. A possible future work would be to replicate this study by presenting a video of real coaches performing the motion sequence. This would enable us to obtain some knowledge regarding the complementary role of kinematics when other communicative modalities are available as performed in Naumann et al. (2009). Another aspect to be considered is the asexual aspect of the 3D manikin: the virtual coach will be sexualized to fit as much as possible a real coach condition. The additional gender information might influence the inference made by observers. Again, replicating this study by presenting a video of real coaches would provide some information regarding the possible influence of gender. A last aspect, which impaired the ability of observers to perceive emotions and personality traits through movement qualities, is the spontaneous nature of our corpus: not intended to be explicitly communicated, social information leaks through kinematics. While accuracy is reduced, this methodological choice enabled us to collect more ecological data. This will ensure the kinematics patterns of our virtual coach are realistic and are not stereotyped.

Overall, this study provides some insights for the design of an interactive virtual fitness coach. While varying movement impulsivity will drive most of the positive and intensity attributions of the coach, dominance and agreeableness are the other two interesting and expressive variables to play with to adapt our coach's movement qualities to the user. Using modern methods for the modeling of stylized movements (Tilmanne and Dutoit 2012), future works will enable us to study the influence of these various attributes conveyed through movement qualities on energy expenditure and engagement in the fitness task.

4. COACH SYNCHRONY: DYADIC ANALYSIS

This section present the second step in the analysis which aims at studying how coach and pupil adapt to each other when jointly performing the predefined motion sequence. Of particular interest is the study of how synchronization patterns are related to individual differences.

After the presentation of the corpus, we proceeded in two steps as in the chapter 4. We first investigate the mutual influence of dyad members in their bodily signature captured by movement qualities. In a second step, we analyze the interactional synchrony using cross lagged correlations. We consider both personality from the pupil and the coach and also analyze the difference between spontaneous and intentional synchronization. In terms of timing, as the movement sequence is predefined, we concentrate the analysis on the evolution of the lag.

4.1. Corpus

4.1.1. Participants and materials

Thirty participants (15 females) took part in the study. Within this population, two groups can be distinguished by their movement skills. The first group was composed by ten participants (5 females) who have special skills in movement performance (i.e., capoeiristas, dancers, and fitness coaches). The second group was composed by twenty participants (10 females) and had never practiced movement performance related sports as the first group. Twenty dyads coach-pupil (matched gender) were formed out of these two groups. Each coach performed the experiment twice which is not an issue as the analysis is made at the dyad level (each formed dyad is different). Participants' movements were collected with a full body motion capture system. The marker setup for each participant was composed of 36 markers. The experiment room was equipped with 18 infrared cameras (V100R2 Optitrack system, frequency: 100 Hz, resolution: 640*480).

4.1.2. Movement sequences

Coach and pupil were asked to learn prior to the experiment a predefined movement sequence: two different feet movements (i.e., step, mounted knee), repeated twice for each side, two different arms movements (i.e., waved arm, uppercut) twice for each side, two combinations of each previous feet and arms movement (i.e., step/wave, mounted knee/uppercut) repeated twice for each side. This movement sequence is the same as in the perceptual study. In addition, coaches were asked to learn a second version of the predefined movement sequence composed of two different feet movements (i.e., mounted knee, heel-cheek), repeated twice for each side, two different arms movements (i.e., uppercut, direct) twice for each side, two combinations of each previous feet and arms movement (i.e., mounted knee/uppercut, heel-cheek/direct) repeated twice for each side. This second movement sequence was unknown from pupils. Participants learned these sequences based on demonstration videos sent to them one week before the experiment. Both choreographies were repeated four times per condition. Two dyads were removed from the corpus due to recurrent errors in the choreographies (learning phase not performed correctly).

4.1.3. Procedure

Each participant was asked to fill a personality questionnaire one week before the data collection (Plaisant et al. 2010). Participants were paid 8€ for each experimental session. Upon arrival, participants were given a consent form, the description of our research aims (i.e., to create an interactive virtual coach) and a description of the task (i.e., to repeat the previously learned choreography four times). Six sequential conditions were designed. Table 44 provides

detailed descriptions of each condition. For the purpose of this PhD thesis, we will concentrate on the task 3 (coach and pupil back to back) and task 4 and 5 (face to face in spontaneous and instructed coordination).

N° Conditions	design	Descriptive
1 trainer	Trainer was alone in the motion capture room. During this time trainee was in another room.	During all conditions, trainers were placed on one of two cross resting on the floor. The crosses were spaced of 2.5 meters. Experimenter asked to trainers to position front of the wall (not in the way where the other cross were) and to realize four times, three following choreographies n°1 when trainer was ready.
2 trainee	Trainee was alone in the motion capture room. During this time trainer was in another room.	During all conditions, trainees were placed on one of two cross resting on the floor. The crosses were spaced of 2.5 meters. Experimenter asked to trainers to position front of the wall (not in the way where the other cross were) and to realize four times, three following choreographies n°1 when trainee was ready.
3	Trainer and trainee were both in the motion capture room back to back.	At beginning of this condition experimenter asked to trainer and trainee to not communicate with voice, gaze or facial expression during all the experimentation. They are positioned as for the first condition (front of the wall, they did not see each other). Experimenter requested then to realize four times, three following choreographies n°1 when they were ready.
4	Trainer and trainee were both in the motion capture room back to back.	At beginning of this condition experimenter communicate to trainer and trainee the role of each one. "For the rest of the experimentation [participant X] you will be the trainer because you are an expert of movements. [Participant Y] you will be the trainee because you have no expertise in dance, fitness coach, etc. This condition was close to the second one. The only change was the announcement of the status in condition 3.
5	Trainer and trainee were both in the motion capture room face to face.	At beginning of this condition experimenter asked to turn face to face. Experimenter requested then to realize four times, three following choreographies n°1 when they were ready.
6	Trainer and trainee were both in the motion capture room face to face.	At beginning of this condition experimenter asked to trainer to teach the choreography number one to the trainee in the goal that he improves the quality of his movements. Since the start of the experiment they did not communicate except with choreography movements. Experimenter asked to trainee to follow the motor instructions of the trainer, that he was the example to follow. Experimenter requested then to realize four times, three following choreographies n°1 when they were ready.
7	Trainer and trainee were both in the motion capture room face to face.	At beginning of this condition experimenter asked to trainer to teach the choreography number two (trainee did not know this one) to the trainee in the goal that he improves the quality of his movements. Experimenter asked to trainee to follow the motor instructions of the trainer, that he was the example to follow. Experimenter requested then to realize four times, three following choreographies n°2 when they were ready.

Table 44: The 7 phases of the protocol in chronological order

4.1.4. Movement qualities computation

Movement data were processed using Matlab R2012b. Positions from nine segments were used: hip, chest, head, arm, forearm, hand, upper-leg, leg, and foot. Five movement qualities were computed for each segment to model the effort-shape domain proposed by Laban (Laban 1950): *impulsiveness* (time), *energy* (weight), *directness* (space), *smoothness* (flow) and *density* (shape qualities). They were averaged on the whole body to obtain one time series per movement sequence per movement quality. Equations to model these qualities are the same as in the perceptual analysis. Because our protocol predefines the movement trajectory, the directness index will only vary according to speed. Therefore, we do not consider it in the analyses. For each movement quality, its static characterization is done with the computation of three features: mean over the bloc (MEAN), standard deviation over the bloc (SD), and mean power frequency over the bloc (MPF).

4.1.5. Personality and experience assessment

Experience about the interaction and personality traits were assessed by self-reporting. Each participant filled in a questionnaire package comprising three self-report questionnaires, namely the five-factor model (Costa and McCrae 1992), which characterizes an individual's personality across five broad traits, namely, extraversion, agreeableness, conscientiousness, neuroticism, and openness (John, Donahue, and Kentle 1991) (French version of the Big Five Inventory was used (Plaisant, Courtois, Réveillère, Mendelsohn, & John, 2010)), the French Toronto Alexithymia Scale (TAS; Loas *et al.*, 2001), which characterizes alexithymia (closely related to emotion regulation) across three factors, each labelled *Difficulties in Identifying Feelings* (*DIF*), *Difficulties in Describing Feelings to others* (DDF), and *Externally Oriented Thinking* (*EOT*). The *DIF* and *DDF* are suggested to reflect affect-related alexithymia, whilst *EOT* is rather cognition-related (Grynberg *et al.*, 2010), and the French Interpersonal Reactivity Index (F-IRI; Gilet *et al.*, 2012) which assesses multidimensional empathy. It is composed of four dimensions: *Empathic Concern* (*EC*), *Perspective Taking* (*PT*), *Personal Distress* (PD), and *Fantasy* (*F*).

Figure 67: One coach and one pupil in a face to face condition of the protocol

4.1.6. Used in this chapter

For the purpose of this chapter which is the analysis of the subtle synchrony between coaches and pupils, and the influence of their mutual personality traits, we need to focus on the elements of this corpus. First, the interpersonal analysis will be done looking only at task 4, 5 and 6. These three phases use only the sequence of movement known by the two participants as we do not want to investigate learning in this PhD thesis. Task 4 is a good conservative baseline to investigate synchrony as both participants are co-present but cannot see each other. This control condition ensures that if synchrony emerges it would be due to visual constrains only. Finally, we will analyze both Task 5 and Task 6 as they represent two different type of context: while Task 6 is an explicit instruction to follow one another, Task 5 provides no guidelines so arising synchrony would be considered as spontaneous.

In terms of personality traits, as in the previous chapter of this PhD thesis we will focus on specific sub-dimensions relevant to our investigations: extraversion, agreeableness and neuroticism from the FFM, the affective component of

alexithymia (composite of DDF and DIF), and Empathic Concern (EC), Perspective Taking (PT), Personal Distress (PD) from the IRI.

4.2. Associations between coaches and pupils behaviors

The first analysis we can run to assess the mutual influences of coaches and pupils on each other is to compare movement qualities of participants between Task 4 (back to back) and Task 5 and Task 6 (face to face). Overall, having a difference in one behavioral variable between these tasks would mean that participants had their behaviors modified while facing each other. As a remark, such an analysis gives no clue on the causality direction. Table 45 presents one repeated measures MANOVA for all behavioral variables with two factors: task represents the three conditions Task 4, Task 5 and Task 6 and Role represents the status of each participant (Coach or Pupil).

Models	Main effect						Post-Hoc			
	Task		Role		Task*Role		T4-T5		T5-T6	
	F	p	F	p	F	p	dif	p	dif	p
Multivariate	3,875	0,000	4,18	0,002	0,98	0,497	X	X	X	X
MEAN_ENE	5,678	,011	,004	,950	,783	,427	-0,08	,012	0,06	,002
MEAN_IMP	3,863	,057	,194	,662	,008	,930	,031	,184	,001	,316
MEAN_JER	4,097	,051	,028	,868	,002	,967	,035	,154	,000	1,000
MEAN_SPA	10,575	,001	,180	,674	,688	,466	-,016	,078	-0,01	,010
SD_ENE	6,160	,009	,363	,551	,640	,479	-0,1	,004	,049	,053
SD_IMP	3,918	,056	1,269	,268	,017	,898	,022	,164	,000	1,000
SD_JER	4,038	,052	,699	,409	,021	,886	,022	,155	,000	1,000
SD_SPA	3,865	,054	,886	,353	,701	,417	,016	,087	-0,01	,000
MPF_ENE	2,782	,103	,002	,967	,081	,790	,114	,176	-0,04	,008
MPF_IMP	1,974	,155	9,462	,004	,003	,994	-,038	1,000	-,155	,196
MPF_JER	5,049	,023	,640	,429	,188	,721	-,537	,168	-,187	,314
MPF_SPA	3,891	,057	,001	,971	,009	,924	,204	,165	-,004	,382

Table 45: MANOVA for all behavioral variables with task (Task 4, Task 5 and Task 6) and Role (Coach or Pupil) as factors with movement qualities features as dependent variables

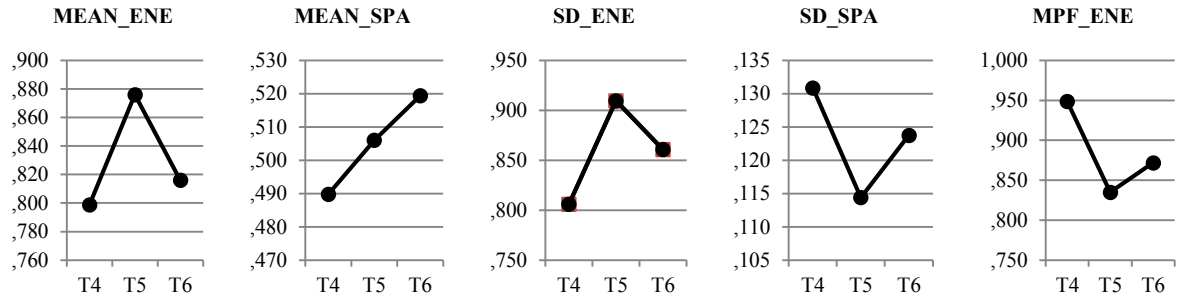


Figure 68: Graphs to visualize the evolution of significant behaviors variables across task 4, 5 and 6

The results clearly evidence differences in movement qualities across the three tasks. These effects were nearly significant for all the movement qualities variables. Looking at post-hoc tests, mean and standard deviation of energy and spatial extent were significant as well as mean power frequency of energy. Figure 68 shows the evolution pattern of these significant variables from task 4 to task 6. We hypothesized from the literature that Task 6 will show a decrease in variability in order to explicitly foster the coordination. Another expectation is that movements are more salient in Task 6 to facilitate guidance. Lastly, task 5 should be noisier than task 4 because individuals are disturbed by the joint but unintentional performance of the other dyad member. The evolution pattern seems in accordance with these considerations. The energy mean and variability increased in task 5 (due to disturbance) but decrease in

task 6 (in order to enable a good coordination). Variables from spatial extent could be interpreted in terms of saliency: the higher mean and variability of spatial extent in task 6 evidence more exaggerated and salient movement patterns. However, this interpretation does not explain why the energy mean power frequency decrease from task 4 to task 5.

A first conclusion of this analysis is that coaches and pupils were influenced when in face to face with the other member. Task 5 is more characterized by disturbance and energy while task 6 is more controlled and salient. A limitation of this analysis is that coaches and pupils did not differ systematically in their styles (only for MPF_IMP), even in interaction with the task factor. Thus, as coaches and pupils do not differ systematically in their original individual style, we cannot further analyze the pattern of convergence of styles. In the case where style differences appear, three possible convergence patterns have been proposed in (Hart et al. 2014) were dyad members can either converge toward the style of one member, converge toward a tradeoff of style or converge toward a new style (Figure 69). This convergence pattern would be an interesting variable to study by selecting divergent style individuals and capturing their convergence.

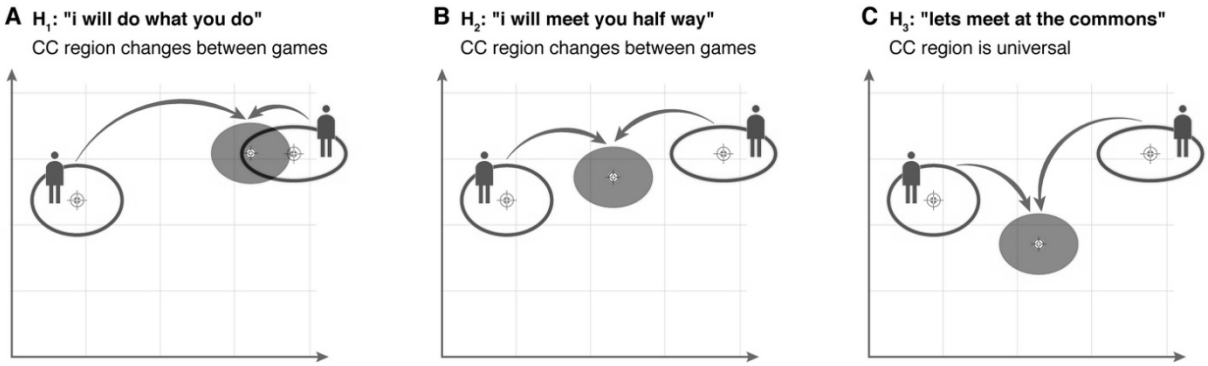


Figure 69: Three possible convergence mechanisms from (Hart et al. 2014), the 2D space representing an abstract expressivity space (e.g., X axis being energy and Y axis being Smoothness)

We now move on the study of the role of individual differences in these mutual adjustments. We computed seven different repeated measures ANCOVA, each with a different individual difference as a covariate. Of particular interest is the interaction effect between Factor and the individual difference. This seven ANCOVA are first performed with Factor representing Task 4 and Task 5 (assess the implicit influence of being face to face) and secondly representing Task 5 and Task 6 (explicit effort to adapt to the other). Within the 7 * 2 models analyzed, only the interaction between T4-T5 and Perspective Taking as well as T5-T6 and Agreeableness had significant univariate effects (Table X). This pattern of result is interesting for several reasons. First, these two traits are both related to pro-social motives and hypothesized to foster greater coordination. The test of mutual adjustment made here does not assess coordination directly but influences which makes hard the direct confrontation of our hypothesis. At least these pro-social traits were coherently associated with some interpersonal processes. The second interesting fact is that the pattern of influence is different between the two traits. As in (Chartrand and Bargh 1999), perspective taking was associated with spontaneous social influence (T4-T5) whereas agreeableness was associated with a different behaviors between the spontaneous and the intentional conditions (T5-T6). As explained in chapter 4, a significant interaction effect at the univariate level indicates that the relation between the covariate (e.g., perspective taking) and the response variable (e.g., MEAN_ENE) differs between groups: an interaction is interpreted as a change in slope of the regression for the different groups. Evidence this change in slope, a possibility is to compute the differences for the response variable between the two groups (e.g., task 4 and task 5), also called gain scores, and investigates the differences in correlations between covariates and task 4 and covariates and gain scores. Table 46 presents the correlation between responses variables and covariates for all the univariate tests which approached significance in perspective taking and agreeableness. While high PT was associated with an energetic

motion sequence less noisy and impulsive in task 4, high PT decreased their energy (mean and variability) and increased impulsivity and jerkiness of their motion sequence from task 4 to task 5. The change in energy amount and variability is in accordance with the hypothesis that high PT induces more smooth and spontaneous coordination, the decrease in variability being a key element to foster good synchronization. However, the enhanced disturbance (impulsivity and jerk) in the motion sequence play against the idea that high PT is related to smoother coordination. However, it is difficult to conclude here as jerkier motion sequences are not necessarily signaling jerkier coordination patterns. High Agree was not associated with any type of motion qualities in task 4, but was significantly associated with a general reduction of variability and jerkiness from task 5 to task 6. This is a clear indication that more agreeable individuals made their motion sequence more predictable for others, but only in the instructed condition. Finally, Empathic concern was hypothesized to be very close to Agreeableness but did not show the same results pattern here. One possibility is that the task includes no emotional events to react on (or others' suffering to alleviate) to activate this pro-social disposition. Together, these results enable us to further build on the fundamental differences which exist between the pro-social related traits. Although apparently sharing a core other oriented disposition, these three traits – perspective taking, empathic concern and agreeableness – are differentially associated with interpersonal bodily processes depending on the task. PT is more related to spontaneous phenomena interpreted as emerging from the natural tendency of high PT to exchange social position and share perspectives, Agreeableness is more related to intentional pro-social behaviors interpreted as the direct conscious effect of communion motives and Empathic concern might foster bodily responses and pro-social acts only in the context of others' suffering and negative emotions.

	Models for T4-T5		**Models for T5-T6**		**Task*PT**				**Task*Agree**			
	Task*PT		**Task*Agree**		**Task 4**		**Task 5-4 gain**		**Task 5**		**Task 6-5 gain**	
	F	p	F	p	r	p	r	p	r	p	r	p
Mutlivariate	1,784	0,11	1,622	0,15								
MEAN_ENE	5,865	0,02	0,582	0,45	,103	,549	-0,384	,021				
MEAN_IMP	3,516	0,07	0,097	0,76	-0,33	,049	,306	,069				
MEAN_JER	3,637	0,07	1,489	0,23	-,322	,056	,311	,065				
MEAN_SPA	1,293	0,26	0,054	0,82								
SD_ENE	6,34	0,02	1,534	0,22	,238	,162	-0,396	,017				
SD_IMP	2,871	0,1	7,17	0,01	-,315	,061	,279	,099	,139	,420	-0,417	,011
SD_JER	2,924	0,1	6,988	0,01	-,326	,052	,281	,096	,118	,493	-0,413	,012
SD_SPA	2,491	0,12	1,912	0,18								
MPF_ENE	2,103	0,16	3,547	0,07					,071	,680	-,307	,068
MPF_IMP	1,796	0,19	7,737	0,01					,107	,534	-0,431	,009
MPF_JER	1,341	0,26	2,144	0,15								
MPF_SPA	2,327	0,14	0,002	0,97								

Table 46: 2 repeated measures ANCOVA where the interaction with an individual difference was significant. When significant, correlations with gain scores are reported.

One issue with our approach is that we consider individual differences at an individual level: scores on agreeableness from coaches and pupils are all labeled under the same name in the analysis. However, individual differences can have multiple different effects: the coaches' traits having a different effect from pupils' traits, the perception of coachs' traits having also an effect on the interaction, etc. Considering individual differences in such truly interactive setup is still a methodological challenge given the many levels of possible variable interactions. Few research works dealt with such truly dyadic analysis and some research frameworks have been developed and recently made accessible. One of the most used is the Actor-Partner Interdependence Model (Cook and Kenny 2005). Within this framework, the actor effect is the effect of an independent variable from individual A on a dependent variable of individual A, and the partner effect is the effect of an independent variable from individual A on a dependent variable of individual B. Such a model in our setup could help differentiate if the movement quality changes of dyad

members were due to coaches, pupils or an interaction of them. However, such model requires structural modeling or multilevel modeling which necessitate large data samples. With only 18 valid dyads, such methods are prohibited (typical studies include at least 100 dyads). This kind of methodological possibility is important to acknowledge for future research.

4.3. Dyad synchrony

In the previous section, we found that dyad members mutually change their movement qualities, toward more disturbances in spontaneous interaction (task 5) and toward more predictability in intentional coordination (task 6). We also found that perspective taking and agreeableness played important moderating roles.

In this section, we propose a more focus analysis by investigated the subtle pattern of synchronization that might arise within the interaction. For this purpose, we consider only the Energy motion quality which is the most directly related to the timing of the movement sequence. As in the previous chapter, we perform a window cross lagged correlation analysis (WCLCA) to investigate the synchronization.

4.3.1. Time window choice

As in the previous chapter, an important parameter to define when running a WCLCA is the time window used to compute the correlations. This time window should be a tradeoff between reliability (bigger time window is better) and sensitivity (smaller time window is better). The sensitivity is particularly important in this chapter as we will analysis the patterns of leading-following within each bloc: a too big time window would erase those subtle variations of lag.

To choose the time window of the WCLCA, we run nine different WLCA with different time window (seconds: 0.25, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4) at 11 different time lags (seconds: -2, -1.5, -1, -0.5, -0.25, 0, 0.25, 0.5, 1, 1.5, 2). Figure 70 present the result of this analysis.

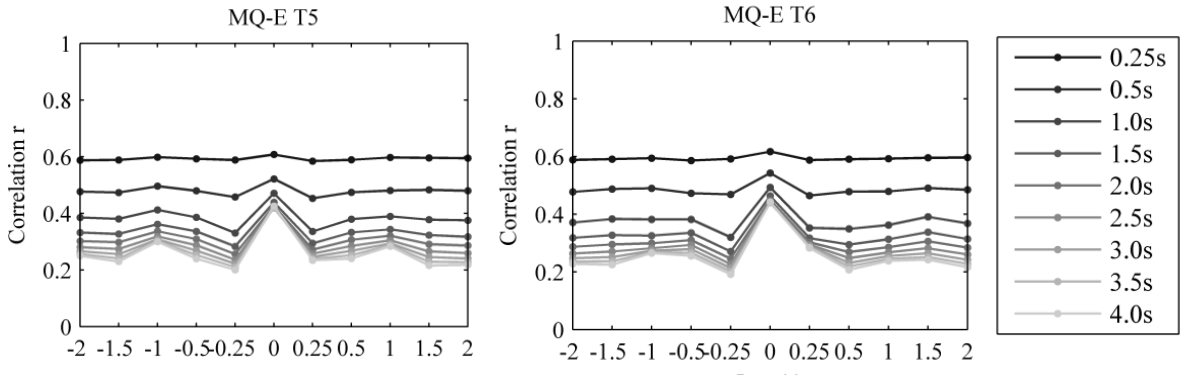


Figure 70: WCLCA on energy data from task 5 and task 6 with different time windows

A clear pattern of higher correlations around lag 0 arises at the time window of 1 second. Subsequent time windows reproduce this pattern, only accentuating it (therefore only increasing reliability). For the following of this chapter, we will use a time window of 1 second. This result is also relevant given the pattern of our movement sequence were each movement within the sequence occur within 1 and 2 seconds.

4.3.2. Other qualities synchrony

We chose to concentrate on the movement quality of energy because of its inherent link with timing (squared speed in the formula). In order to verify that the three other movement qualities are not more relevant for the study of synchronization than energy, we computed the WCLCA for all dyads and all other movement qualities. All correlation maps were interpolated in order to make the same length and averaging them for each movement quality. Figure 71 presents the average correlation maps resulting from this calculus. Interestingly, only the energy correlation map shows a relatively constant pattern of correlation across time, whereas other movement qualities show time zones were correlations are notably higher. We interpret this visualization as evidence that movement qualities other than energy are dependent of the type of movement performed. For example, the spatial extent correlation map show really high correlation patterns only for the movement phase were foot moves are involves. This result confirms our choice to focus on energy to measure the synchronization pattern.

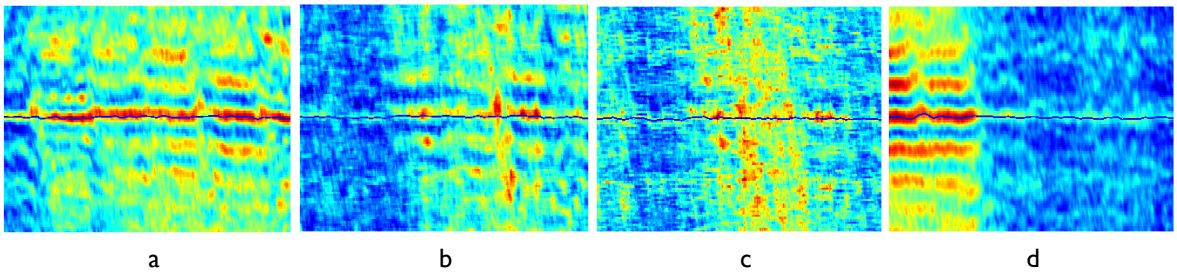
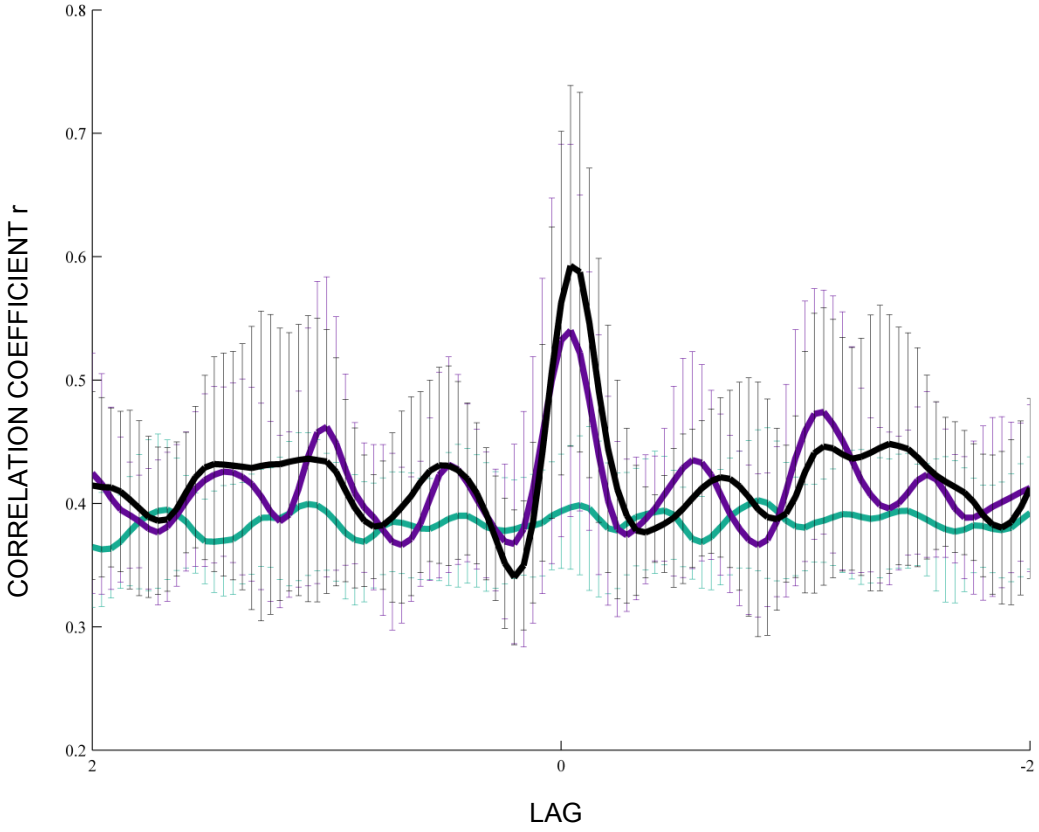


Figure 71: WCLCA averaged over all sequence for a) energy b) impulsivity c) jerkiness d) spatial extent

4.3.3. Global synchrony

We now aim to quantify the synchronization pattern across tasks. Using a time window of 1 second, WCLCA are run on the 18 dyads with a lag ranging from -2 to 2 seconds for task 4, 5 and 6. We computed the WCLCA for task 4 (back to back) in order to define a control group. Such control is more conservative than the method used in chapter 4 (building pseudo-pairs) as in include the dyad members styles. Figure 72 presents the averaged correlation over lags for all 18 dyads. Averages of correlation are done using fisher transformations.

The maximum correlation when participant are face to face occur at the same time lag (+ 4 frames) with r =0.5402 for Task 5 and with r =0.5926 for Task 6. At this lag, Task 4 shows a correlation of 0.3968. Mean comparisons revealed that T5 peak correlation was significantly higher than for T4 $t(17)=-5.8370$, $p<0.000$, T6 peak correlation was significantly higher than for T4 $t(17)=-7.2182$, $p<0.000$ and that T6 peak correlation was significantly higher than T5 peak correlation $t(17)=-2.2858$, $p=0.035$. Thus, participants automatically synchronized even when not told (Task 5) and increase this synchronization when asked compared to this spontaneous synchronization. Additionally, the difference in magnitude of synchronization between spontaneous and intentional setup is not very large compared to task 4: most of the coordination emerge spontaneously.



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and the red graph is for real dyads for Task 4 (back to back).

4.3.4. Peak picking

As in the study of synchronization in chapter 4, results from the WCLCA provide us two indicators to study individual differences in synchrony: peak correlation near lag 0 and lag of this peak correlation. In the specific context of the fitness task where the two dyad members perform the same movement sequence, additional analyses can provide more detailed evaluation of the leading/following pattern during synchronization. The analysis of the evolution of synchronization lag was introduce by (Boker et al. 2002). The idea is to pick the maximum correlation near lag 0 at each frame during the interaction. This operation requires some parameterizations and smoothing but is of particular value when the setup induces the joint performance of the same movement. This provides a new time series of lag of maximum correlation across time. This analysis was not possible for the COMPARSE corpus as behaviors pattern were extremely dissimilar which make such evaluation impossible.

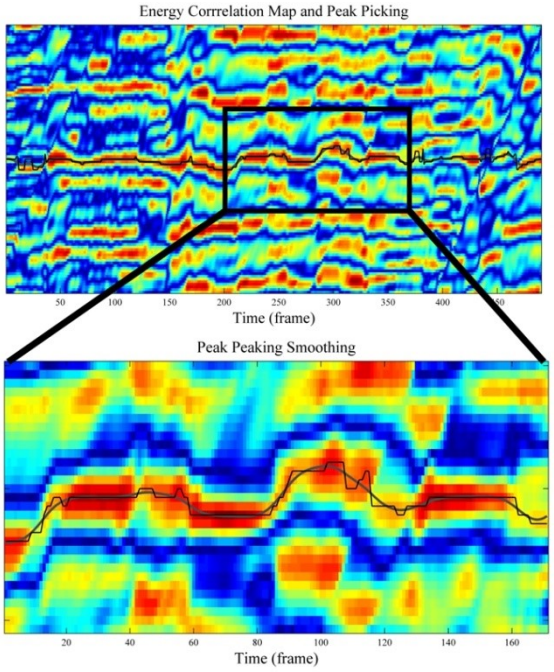

Figure 73: Example of peak picking in a WCLCA

In this corpus, each participant performs exactly the same movement sequence which ensures a smooth continuity in maximum correlation near lag 0. In this corpus, a negative lag means that the pupil is late compared to the coach. Figure 73 shows an example of the resulting time-series for one bloc and a zoom to show the effect of the peak picking smoothing.

From this new time-series, several variables can be extracted. In this chapter, we compute the mean lag (PP_MEAN_LAG), mean correlation at peaks (PP_MEAN_CORR), standard deviation of the lag (PP_SD_LAG), number of time within each bloc that the opposition leader/follower switch (PP_NB_SWITCH) and the percentage of time that the coach is leading the interaction (PP_PERC_LEAD). To our knowledge, no study investigated such lag related variables. Although the simple study of lag at maximum correlation can be driven by fairly robust hypotheses, the computation of these alternative variables is exploratory and based on more tentative assumptions.

Table 47 show the inter-correlations between these variables in our corpus for the two task 5 and 6 (n=36). As can be expected, most variables are correlated as they all deal with the synchronization patterns. We look at correlation above 0.8 indicating a very high shared variance and suggesting the identity of the two variables: the mean lag was almost equivalent to the percentage of leading (r=0,917) and the mean correlation at picked lag was almost equivalent to the maximum correlation found from classical analyses (r=0,943). Additionally, the mean power frequency of the lag time series was close to the number of switch of leading following patterns (r=0,798) representing the variability of in this pattern (higher values indicate more alternation).

		PP_MEAN_LAG	PP_STD_LAG	PP_MPF_LAG	PP_MEAN_CORR	PP_NBSWITCH	PP_PERCLEAD	CC_MAX_CORR	CC_MAX_CORR_LAG
PP_MEAN_LAG	r	1	-0,183	-0,253	0,214	-0,647	0,917	0,332	0,635
	p		0,284	0,137	0,211	0,000	0,000	0,048	0,000
PP_STD_LAG	r		1,000	0,310	-0,299	0,454	-0,464	-0,483	-0,203
	p			0,066	0,077	0,005	0,004	0,003	0,236
PP_MPF_LAG	r			1,000	-0,330	0,798	-0,276	-0,373	-0,227
	p				0,049	0,000	0,103	0,025	0,184
PP_MEAN_CORR	r				1,000	-0,556	0,253	0,943	0,154
	p					0,000	0,137	0,000	0,370
PP_NBSWITCH	r					1,000	-0,691	-0,646	-0,443
	p						0,000	0,000	0,007
PP_PERC_LEAD	r						1,000	0,416	0,609
	p							0,012	0,000
CC_MAX_CORR	r							1,000	0,243
	p								0,153
CC_MAX_CORR_LAG	r								1,000
	p								

Table 47: zero order inter-correlation for the 8 lag variables

4.3.5. Individual differences in synchrony

To study how individual differences are related to synchronization patterns, we run two separate analyses on task 5 first and task 6 secondly. We keep them separately given the different nature of the interpersonal bodily processes at play in each (spontaneous and intentional) and the confirming evidences of the previous analysis. Additionally, we took into account the asymmetrical nature of the task: one coach and one pupil. Therefore, we compute separate correlations for coaches (rCo) and pupils (rPu). Lastly, we run multiple linear regressions to investigate if the

respective dispositions of coaches and pupils as well as the interaction between them explain a significant part of the synchronization pattern variance.

We first begin by the analysis of task 5. We computed the correlations and multiple regressions between lag variables and selected individual differences and evidenced some significant results. Table 48 presents the individual differences which did have some significant results. As expected from the literature and the previous analysis, PT was associated with lag variables in this spontaneous condition. More specifically, mostly the pupil PT disposition was associated general lag (PP_MEAN_LAG and CC_MAX_COR_LAG): high PT pupils performed the motion sequence with significantly more lag compared to the coach. Together with a significant interaction, this trait explained about 60% of the variance in general lag. The pattern of associations of extraversion and alexithymia appeared to be symmetrically different from perspective taking. General lag (PP_MEAN_LAG, PP_PERC_LEAD and CC_MAX_COR_LAG) were associated with coaches dispositions in extraversion and alexithymia: high extrovert and low alexithymic coaches were more in advance in the motion sequence, explaining about 45% of general lag in the multiple regression. The fact that extraversion and alexithymia show the exact same pattern calls for caution. Computing the pairwise correlation between extraversion and alexithymia in our small sampled revealed a high inverse correlation (r = -0.654, p<0,000) making difficult to disentangle their respective effects. As the results are about lag and initiative in the interaction, we prefer interpret it in terms of agency as our initial hypotheses would predict: extroverted individuals take the initiative in the spontaneous interaction. In this task, PT was not associated with more synchrony by rather to timing of synchronization: higher PT lead to less initiative in the interaction probably as a way to respect a leader – follower schema to enable a smoother coordination.

		Extra											
		rCo	p	rPu	p	r2	p	βCo	p	βPu	p	βCoPu	p
T5	PP_MEAN_LAG	-0,63	0,01	-0,18	0,46	0,45	0,03	-0,38	0,01	-0,12	0,32	0,07	0,50
	PP_STD_LAG	0,23	0,35	-0,22	0,38	0,12	0,59	0,06	0,39	-0,07	0,35	0,04	0,60
	PP_MPF_LAG	0,24	0,33	0,07	0,79	0,08	0,76	0,02	0,34	0,01	0,74	-0,01	0,64
	PP_MEAN_COR	0,01	0,97	-0,18	0,48	0,03	0,93	0,00	0,96	-0,02	0,53	0,00	0,95
	PP_NBSWITCH	0,39	0,11	0,25	0,32	0,22	0,32	3,00	0,12	1,81	0,31	-0,17	0,92
	PP_PERC_LEAD	-0,65	0,00	-0,08	0,77	0,42	0,05	-0,07	0,01	-0,01	0,70	0,00	0,84
	CC_MAX_COR	-0,02	0,95	-0,13	0,62	0,02	0,96	0,00	0,97	-0,01	0,68	-0,01	0,81
	CC_MAX_COR_LAG	-0,51	0,03	-0,11	0,66	0,28	0,19	-0,76	0,04	-0,13	0,69	-0,11	0,72
		Alex											
		rCo	p	rPu	p	r2	p	βCo	p	βPu	p	βCoPu	p
	PP_MEAN_LAG	0,60	0,01	0,30	0,23	0,50	0,02	0,29	0,01	0,29	0,12	-0,04	0,83
	PP_STD_LAG	-0,02	0,94	0,32	0,20	0,12	0,61	0,02	0,74	0,16	0,19	0,07	0,60
	PP_MPF_LAG	-0,39	0,11	0,05	0,85	0,21	0,34	-0,03	0,08	-0,01	0,65	-0,03	0,34
	PP_MEAN_COR	0,01	0,98	-0,09	0,73	0,02	0,97	-0,01	0,85	-0,02	0,65	-0,02	0,71
	PP_NBSWITCH	-0,44	0,07	-0,09	0,73	0,22	0,31	-2,76	0,12	-1,47	0,60	0,14	0,97
	PP_PERC_LEAD	0,46	0,05	0,18	0,47	0,29	0,17	0,04	0,13	0,03	0,51	-0,03	0,57
	CC_MAX_COR	-0,03	0,91	-0,09	0,72	0,02	0,96	-0,01	0,74	-0,02	0,62	-0,02	0,69
	CC_MAX_COR_LAG	0,48	0,04	0,39	0,11	0,47	0,03	0,53	0,07	0,77	0,11	-0,43	0,41
		PT											
		rCo	p	rPu	p	r2	p	βCo	p	βPu	p	βCoPu	p
	PP_MEAN_LAG	0,10	0,68	-0,45	0,06	0,42	0,05	0,12	0,28	-0,51	0,01	-0,31	0,04
	PP_STD_LAG	0,01	0,97	0,03	0,92	0,13	0,57	-0,02	0,79	0,09	0,35	0,12	0,17
	PP_MPF_LAG	-0,32	0,20	-0,14	0,57	0,20	0,35	-0,03	0,15	0,01	0,72	0,03	0,24
	PP_MEAN_COR	0,17	0,51	0,41	0,09	0,19	0,38	0,01	0,54	0,04	0,28	-0,01	0,77
	PP_NBSWITCH	-0,35	0,15	0,00	1,00	0,26	0,23	-2,97	0,09	2,49	0,31	3,23	0,14
	PP_PERC_LEAD	0,05	0,85	-0,43	0,08	0,41	0,05	0,02	0,40	-0,09	0,01	-0,06	0,04
	CC_MAX_COR	0,19	0,46	0,36	0,14	0,18	0,40	0,02	0,43	0,03	0,50	-0,02	0,49
	CC_MAX_COR_LAG	-0,01	0,96	-0,62	0,01	0,60	0,00	0,18	0,47	-1,57	0,00	-0,82	0,02

Table 48: correlations and multiple regressions with individual differences as predictors of lag variables in task 5

We then computed the correlations and multiple regressions between lag variables and selected individual differences for task 6. Table 49 presents the individual differences which did have some significant results. Globally, we found less individual differences influences on synchronization pattern in this task 6 which was expected: instructed to coordinate, individuals behave in a more standard uniformed way. As found in the previous analysis, agreeableness played a significant role in modulating this interaction: agreeable coaches significantly reduced the variability of leading – following alternation and agreeable pupils were significantly less late compared to coaches. Together, these two effects provide clear evidence about how agreeableness contributes to a smoother interaction. Both neuroticism (only the interaction) and alexithymia (of the pupils) were associated with greater lag amplitude variability: being worst in emotion regulation induce larger deviation from lag 0, either in advance or late direction. This result is highly valuable as it seems to be related to the quality of the synchronization pattern: a smooth coordination could be conceptualized as a stable level of lag, independently of its mean (PP_MEAN_LAG) or its temporal variations (PP_MPF_LAG). Thus, greater amplitude in lag variation is directly associated with less smooth coordination. This result is therefore in line with our hypothesis that affective alexithymia is associated with weaker quality of coordination, although we did not expected that the effect would appear in the intentional condition only.

		Agree											
		rCo	p	rPu	p	r2	p	βCo	p	βPu	p	βCoPu	p
T6	PP_MEAN_LAG	0,14	0,57	0,40	0,10	0,20	0,36	0,04	0,83	0,15	0,19	-0,13	0,44
	PP_STD_LAG	-0,16	0,52	-0,38	0,12	0,16	0,48	-0,03	0,77	-0,07	0,21	0,03	0,69
	PP_MPF_LAG	-0,55	0,02	-0,20	0,42	0,32	0,13	-0,06	0,03	0,00	0,86	0,01	0,52
	PP_MEAN_COR	-0,07	0,78	-0,03	0,91	0,07	0,79	-0,01	0,82	0,00	0,83	-0,03	0,34
	PP_NBSWITCH	-0,31	0,21	-0,36	0,14	0,30	0,16	-2,26	0,30	-1,25	0,33	2,88	0,15
	PP_PERC_LEAD	0,20	0,42	0,49	0,04	0,27	0,20	0,01	0,70	0,03	0,09	-0,02	0,45
	CC_MAX_COR	0,03	0,89	0,13	0,60	0,08	0,75	0,00	0,97	0,01	0,75	-0,03	0,35
	CC_MAX_COR_LAG	0,23	0,36	0,33	0,19	0,19	0,38	0,45	0,52	0,38	0,36	-0,63	0,32
		Neuro											
		rCo	p	rPu	p	r2	p	βCo	p	βPu	p	βCoPu	p
	PP_MEAN_LAG	-0,11	0,67	-0,21	0,40	0,05	0,85	-0,04	0,81	-0,10	0,45	-0,03	0,81
	PP_STD_LAG	-0,24	0,34	0,11	0,68	0,57	0,01	-0,07	0,15	0,01	0,86	-0,17	0,00
	PP_MPF_LAG	-0,25	0,31	-0,21	0,40	0,09	0,72	-0,02	0,42	-0,01	0,55	0,00	0,95
	PP_MEAN_COR	-0,06	0,81	0,01	0,95	0,04	0,91	-0,01	0,81	0,01	0,82	0,02	0,51
	PP_NBSWITCH	-0,03	0,92	0,04	0,89	0,05	0,87	-0,23	0,90	0,01	0,99	-1,38	0,42
	PP_PERC_LEAD	0,09	0,72	-0,11	0,65	0,06	0,82	0,01	0,66	-0,01	0,70	0,02	0,48
	CC_MAX_COR	0,02	0,94	-0,02	0,94	0,07	0,79	0,00	0,93	0,00	0,92	0,03	0,33
	CC_MAX_COR_LAG	-0,20	0,42	-0,01	0,97	0,05	0,86	-0,42	0,45	0,03	0,95	-0,18	0,73
		Alex											
		rCo	p	rPu	p	r2	p	βCo	p	βPu	p	βCoPu	p
	PP_MEAN_LAG	-0,16	0,52	0,27	0,28	0,26	0,23	0,05	0,69	0,34	0,09	0,38	0,09
	PP_STD_LAG	0,22	0,37	0,58	0,01	0,46	0,03	0,04	0,41	0,17	0,04	-0,08	0,34
	PP_MPF_LAG	-0,28	0,26	0,09	0,73	0,30	0,15	-0,03	0,05	-0,02	0,44	-0,06	0,05
	PP_MEAN_COR	-0,14	0,57	-0,05	0,84	0,03	0,92	-0,01	0,74	0,00	0,94	0,01	0,74
	PP_NBSWITCH	-0,04	0,88	0,06	0,81	0,27	0,21	-1,65	0,24	-1,87	0,43	-5,72	0,04
	PP_PERC_LEAD	-0,14	0,58	0,02	0,93	0,17	0,44	0,01	0,78	0,02	0,46	0,06	0,13
	CC_MAX_COR	-0,19	0,46	-0,13	0,62	0,09	0,70	-0,01	0,75	-0,01	0,86	0,03	0,47
	CC_MAX_COR_LAG	-0,27	0,27	0,31	0,21	0,23	0,28	-0,12	0,78	1,12	0,13	0,96	0,24

Table 49: correlations and multiple regressions with individual differences as predictors of lag variables in task 6

4.3.6. Discussion

In this section, we undertook the analysis of an interactive fitness task where coaches and pupils perform the same movement sequence. Within the corpus, we focused on three tasks enabling to investigate different types of coordination (spontaneous and intentional): task 4 is the performance of the motion sequence without visual contact, task 5 is the performance of the task with visual contact without instructions to coordinate and task 6 is the performance of the task with visual contact with the explicit instruction that the pupil should follow the coach. To investigate the mutual nonverbal adjustments between the dyad members, we relied on the characterization of motion via movement qualities. Four movement qualities – energy, impulsivity, jerkiness and spatial extent – were used in the first analysis. The aim was to compare dyad members' bodily signature between tasks and find out if they globally were influenced by each other. The conclusion of this analysis was that coaches and pupils were influenced when in face to face with the other member, Task 5 being more characterized by disturbance and energy while task 6 being more controlled and salient to foster a smooth coordination. For the second analysis, we concentrated on the analysis of synchrony as quantified by cross correlations based solely on the energy movement quality. At the task level, dyad members did synchronize in both task 5 and 6. Although the result was expected, the magnitude of the interactional synchrony was almost the same between task 5 and 6 revealing the power of spontaneous interactional synchrony.

In both analyses we systematically investigated the modulation of the results by selected individual differences. The changes in bodily signature across tasks highlighted the key role of perspective taking in spontaneous conditions (task 5) and agreeableness in intentional conditions (task 6). High PT individuals showed reduce energy and variability and increased jerkiness in task 5, perhaps a sign that these individuals were more attentive to the other dyad member inducing more self-other interferences. Complementarily, high Agreeableness was significantly associated with a general reduction of variability and jerkiness from task 5 to task 6. This is a clear indication that more agreeable individuals made their motion sequence more predictable for others, but only in the instructed condition. These interpretations were confirmed in the synchrony analysis. High agreeable individuals had smoother coordination patterns only for task 6; with agreeable coaches having smoother lag patterns and agreeable pupils taking the follower role (more lag). Also, high perspective taking individuals had more adjusted synchronization patterns in task 5: high perspective taking pupils had significantly greater lags to avoid overlapping and disturbing interference during spontaneous motions. Regarding these two traits, our results only partially validate our hypotheses: although PT seems to be associated with behaviors related to smooth adaptation to others (reducing variability and adjust timing to not interfere with the other), we found no evidences of greater quantity of synchronization. Also, leadership could not be associated with it given our interpretation of what is a good adaptation in the spontaneous conditions (being late). Regarding agreeableness, we hypothesized that the inherent pro-social motivation of the trait would lead to greater synchrony. Our results evidenced that agreeable people are rather better synchronizer in terms of quality by reducing jerkiness and improving predictability. Our results also precise that this effect does not occur in spontaneous conditions: as in studies investigating pro-social behaviors, it is only under intention that the trait characteristics are activated. The result associated with extraversion confirmed our initial hypothesis: in spontaneous conditions where uncertainty about leader roles exists, extroverted individuals take more the lead. Affective alexithymia was also related to synchrony variables which seem to appear in line with our initial hypothesis: greater alexithymia was associated with greater amplitude variations in lag evidencing a bulky evolution of lag throughout the movement sequence. The fact that this result appeared only in the intentional task was not expected and further theoretical investigation would be required to capture this specificity. Lastly, personal distress and empathic concern were not associated with any phenomena. We interpret this fact as a contextual reason: without the presence of other emotional expression to foster the empathic process, the dispositions related to empathy are not relevant.

Altogether, these analyses provided insightful results partially confirming some of our hypotheses and calling for more detailed contextualization of the theory: systematically, we interpreted the result by taking into account the nature of the task (spontaneous versus intentional) and the role of each individual (coaches versus pupils). A major limitation of our study is the very small sample (n=18) which limits the generalizability of our result to larger population. Also, in addition to the risk of the sample population, the correlations reliabilities are inherently not very high making our results fragile against outliers or other biases. Future works should try to increase the sample size: this would avoid the listed limitations as well as enabling structural equation modeling statistics which would help understanding the interplay of dyadic dispositions (actor and partner effect).

As a general conclusion, this corpus revealed the potential usefulness of considering individual differences in interpersonal bodily processes, either in spontaneous or intentional joint actions. It clearly appeared that digging into the concept of synchronization patterns via the computation of lag related variables could be really prolific. Future researches could attempt to study these patterns in more details in a multivariate way.

5. TOWARD A VIRTUAL COACH

The study of the fitness coach task revealed several encouraging results which can be used as a good ground to develop a virtual coach: movement qualities from coaches can convey positivity, agreeableness and dominance – three relevant dimensions for the development of a virtual coach – and dyad members synchronize spontaneously and intentionally as a function of individual differences. For both issues, two motion capture corpus are available to fuel the animation module of a potential virtual coach. The last step of our work regarding this case study is to lay the ground for the development of an interactive virtual coach which could reproduce these various effects.

5.1. Goals of the virtual coach

The development and study of exergames in the HCI community is gaining increasing interest. The use of full body interactive virtual coaches in this literature is reduced to the role of avatars (reproducing exactly what the user does), to the role of asynchronous demonstrators (showing a movement to perform) or as opponents to fight in sports scenario. A couple of past projects attempted to build interactive virtual humans in sports tasks (Ruttkay et al. 2006)(Billon, Nédélec, and Tisseau 2010) with few evaluations to assess the validity of the model and the long term effect on users. One characteristic of this PhD thesis is to emphasize the essential role of the subtle and spontaneous coupling which emerges during any social interaction. In this section, we describe the different key elements to build an interactive virtual coach with a focus on two aspects: the evolution of interactional synchrony during the joint performance of a predefined movement sequence (evolution of lag) and the expressivity of the motion sequence performed by the coach. We argue that such a low level social tuning provide the ground for a deep social presence feeling (Biocca, Harms, and Burgoon 2003), a necessary step toward a more engaging application.

The development of this virtual coach is done with two goals in mind:

- The future development of an application which could encourage individuals to undertook fitness sessions at home. In such application driven goal, the believability of the virtual character interactive behaviors is essential and the motivational support provided through the motion kinematic of primary importance.
- The future development of an experimental tool which could help scientists to investigate how individuals synchronize intentionally and spontaneously while performing a predefined motion sequence in a much more easy and controlled way. By grounding the design of the interactive behaviors of the virtual coach (reproducing a real word interactive pattern in a data driven approach), the application could serve an experimental purpose.

In this section, we present the functional design of such an application as a proof of concept to be developed (after this PhD thesis). In order to stick to our data analysis, we focus on the dyad members' movement qualities without considering facial expressions and gaze. These channels could be analyzed and implemented in future steps following the same approach as in this thesis.

5.2. Virtual coach design

5.2.1. Scanned 3D model

High definition 3D models of individuals in sport wears are easily found to be used in our application. However, in order to stay as close as possible from our experiments we should found a 3D avatar which is gender matched (we need one man and one woman) in a motion capture suit. This fidelity to the experimental protocol is a condition to ensure the possible comparison with our real data and move toward the design of a virtual coach as an experimental tool.

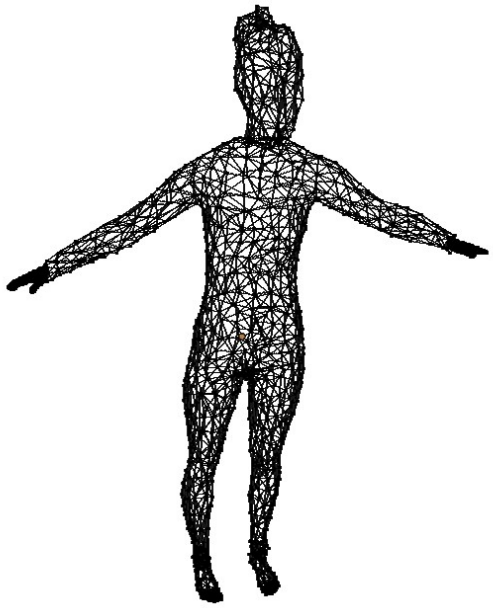

Figure 74: 3D mesh captured for the woman coach

As such model is not easily found, we decided to create our own via a 3D scan procedure of two individuals (man and woman) wearing our motion capture suit. This procedure is nowadays accessible thanks to the development of powerful computers, the availability of low cost 3D sensors such as the kinect and the use of dedicated 3D reconstruction software.

Figure 74 presents the first step of this procedure which is the acquisition of the 3D mesh. With the addition of texture based on photos, the rigging (construction of the skeleton to animate) and the skinning (weighting of the mesh on the skeleton), this 3D mesh is ready to be animated. No details are necessary for the face as it will be blurred as in chapter 4. Hands will be in the same close position during the whole task.

5.2.2. Nonverbal behaviors: expressivity and synchrony

In this chapter, we deliberately tackled issues related to expressivity and issues related to interactional synchrony separately. For sure they closely interact, both directly – when synchronizing to an individual who is energetic, the individual style become also energetic – and indirectly – the expressivity level is intimately linked to the individual state (e.g., emotions or attitudes) which modulate the synchronization pattern (a more tense motion sequence could signify a negative attitude and impaired the smooth coordination of both partners) –. But given the novelty of our approach, the dichotomization of these two aspects is a first step before more integration.

Expressivity

A fitness session is the performance of repeated and energetic movements. In essence, the task is based on predefined movement sequence and it is the way an individual performs it that determines his/here energy expenditure,

motivation, etc. The modeling of such variations as been coined motion styles in the motion synthesis literature (in opposition to works dealing with the interpolation of sequential motion sequences such as walking to running) (Van Welbergen et al. 2010). In this chapter, we presented the collect of a corpus which includes motion capture data of the same movement sequences performed by different coaches under different contexts. A perceptual study on one part of the corpus (56 motion sequence) provides expressivity labels: positivity, agreeableness and dominance. This database enables us to envisage the definition of several level of expressivity for the virtual coach. The development and evaluation of this synthesis of expressive motion sequence is out of the scope of this PhD thesis and will constitute a promising line of research. In the following, we present some first elements of this approach.

One straightforward possibility to generate expressive motions is to chose and play the motion sequence with the expressive labels close from the desired level of expressivity. An alternative is to build on the existing literature of data-driven motion synthesis of stylized movements. Researches on the synthesis of stylized animation from motion capture data is currently gaining interest with various techniques developed such as regressions (Torresani, Hackney, and Bregler 2007), hidden markov models (J. Tilmanne and Dutoit 2011) or principal component analysis (Urtasun et al. 2004). The research topics deal with several challenges such as the quality of the synthesized motion (regarding original motions and believability), the continuous control of style variations, the interpolation of stylized motions or the generation of new styles not present in the existing data set. For the future development of the virtual coach, we do not wish to generate new styles, interpolate styles or continuously vary the presented style. Our first goal is to generate predefined (which cannot vary from one style to another) stylized motion sequence. The PCA based approach proposed in (Joëlle Tilmanne and Dutoit 2010) appears to fit our goals: it requires to time scale all sequence to make them fit into the same space in order to extract the principal components. The resulting styles are time independent which is consistent with our assumption to separate synchrony and expressivity. The main risk of such approach is that removing the variation in mean speed over all sequence would erase the perceived expressivity. Future researches should investigate what is lost with this assumption.

Synchrony

The second aspect of the development of our virtual coach is the interactive nature of the motion synthesis. While the virtual coach performs the predefined motion sequence in a given style, the online evolution of the sequence should subtly adjust to the evolution of the pupil motion sequence evolution.

Within our analysis of the synchronization patterns during the fitness task, we relied mainly on the patterns of lag during sessions: dyad members move in and out synchronization being alternatively late and in advance in the motion sequence. Interestingly, these patterns were very sensitive to the individual differences of both coaches and pupils. This "*lag management*" is a good starting point toward a truly interactive virtual coach as lag is a variable inherently interpersonal.

Works attempting to predict joint movements in dyadic setup are scarce. Recently, (Yang, Metallinou, and Narayanan 2014) presented a very insightful study about the prediction of movement of one dyad member from the movement of the other dyad member or alternatively put: "*automatically predicting the body language of an interacting participant from the speech and gesture behavior of an interlocutor*". Although they included in their feature selection phase some dyadic variables (e.g., interpersonal distance), their approach can best be defined as a reactive model rather than interactive: one member movements determines the other member's movements. Of course this type of model become interactive indirectly – member A motions are determines by member B motions which are influenced by the later member A motions –, but the model does not address directly this feedback loop. In our corpus, we extracted the evolution of lag via the method of peak picking. We propose to base our interactive model on the prediction of this interactive lag which inherently includes the relative position of one member compared to the other. Being able to predict online this lag time series appears to be an interesting first step toward

the modeling of a "*truly*" interactive virtual coach. In this following, we present a first attempt to predict this time series via regression analysis.

5.3. Software architecture

The software architecture is essentially the same as in chapter 4: a sensing module using the SSI framework (Wagner et al.), a synthesis module playing and interpolating the animations using the ADAPT framework (Shoulson et al. 2013), a rendering module developed in Unity and a decision module which link the sensing and the synthesis module to provide information of lag evolution.

For the purpose of this application, the sensing module takes as input data the motion capture system as in the corpus. Motion qualities from the full body movement are computed in real time. The synthesis module takes as input the predefined stylized motion sequence (either directly from the corpus or from the generated stylized motions) as well as the prediction of lag. This later information indicates when to slow down or accelerate in the motion sequence regarding the co-evolution of the dyad movements. The decision module aims at predicting this lag to use for the motion synthesis. The determination of the lag is the object of the prediction algorithm described in the next section.

5.4. Synchrony management

The aim of this section is to present our prediction approach. This thesis being interdisciplinary, we purposely chose to keep our approach as simple as possible to make possible the study of all the components in one thesis. Machine learning and prediction is whole subject and our strategy is to propose a simple model which demonstrates the possibility to develop further such research.

5.4.1. Methodology

In the previous section, we reduced the complex issue of the modeling of interactive behaviors to the prediction of the lag time-series. Although this minimalist approach has limitations, it provides a sound first step toward the development of an interactive virtual coach.

The prediction problem is the prediction of a continuous time-series by other continuous times-series. The most straightforward way to tackle such a problem is via linear regressions. Such an approach might not provide the best possible results but can be understood as a good proof of concept to undertake further researches on possible prediction strategies.

5.4.2. Feature extraction and selection

In our corpus, we characterize motion sequences via four different movement qualities: energy, impulsivity, jerkiness and spatial extent. Our analysis of interactional synchrony led us to choose a time window of 1 second for the analysis of lag evolution. Using this same time window, we can characterize each time-series via descriptors at each frames describing the 1 second time window before the frame (100 data points with our motion capture systems). As in the chapter 4, we extract variables from each time-series: minimum, maximum, mean, standard deviation, energy, index of dispersion, mean power frequency and peak frequency.

The lag variable is merely interactive. Thus, we extract descriptors from both dyad members. In addition, the relative position of one dyad member compare to the other might also be relevant for the prediction of the lag. We compute

the difference between movement qualities from coach members and movement qualities from pupils' members, leading to the creation of four new time-series: difference in energy, difference in impulsivity, difference in jerkiness and difference in spatial extent. The same 8 variables are computed on these four time-series. In total, we extract from these process 96 variables at each data point.

In chapter 4, we undertook the feature selection phase separately from the prediction experiment and in two steps: removing redundant variables and performing a forward sequential feature selection. For the virtual coach, we tried an alternative approach based on modern development in regression model: regularization methods such as rigde, lasso or elastic net regression enable to reduce the number of predictors automatically while preventing from over-fitting. As a first step, we use lasso regression for feature selection. This step will be done within the training-validation phase, the resulting selection of variables being use on the test set. With this approach, each fold will potentially select a different set of variables which can be inspected to see recurrently selected variables and evaluate the stability of this selection.

5.4.3. Prediction experiment

The prediction will be done separately for task 5 and task 6 as they represent two different ways to synchronize (spontaneous versus intentional). We expect that the prediction of lag in task 6 might perform better that task 5 as individuals as instructed to coordinate and deliberately make each other predictable. Task 5 is composed of 64 motion sequences and task 6 is composed of 65 motions sequences.

For the training and evaluation of our prediction model based in the 96 variables, we followed a classical train-validation-test procedure. First all the motion sequences are separated in 10 equal classes. At each step of the 10 folds, one fold (about 6 motion sequences) is kept for testing purpose and the rest is used for training-validation. The training-validation phase is done with a 5 folds procedure training our lasso regression: repeating five times the training on about 47 sequences and validating on the remaining 11 sequences. During this step, the lasso regression algorithm selects the adequate number of variables to minimize the mean square error. This procedure is done separately for task 5 and task 6. The resulting predicted lag from the defined model is evaluated with both the correlation coefficient to the original data (co-variation measure) as well as the Root Mean Square Error (distance measure).

In our case and without studies available on the analysis of this kind of task, our ground truth is a static lag model: a fixed lag is determined to minimize the RMSE. This ground truth is very limited as it does not vary with time and therefore won't correlate with the original data. Given the oscillatory nature of the lag, a more conservative ground truth would be to fit a sinusoid instead.

Figure 75 shows the results of the prediction algorithms. Looking at the ranking of the 96 variables selected by the lasso regression algorithm, the top ranked variables and last ranked variables appear consistent across the 10 folds which show some stability. Looking at the overall patterns, the selection of variables appears more stable for task 6 but without clear distinction. The result from the prediction algorithm does not perform better than our fixed threshold model in terms of RMSE. No differences also appeared between task 5 and task 6 for the RMSE measure. However, the prediction for task 5 appeared significantly more correlated to the original data (r= 0,1412) than the prediction for task 6. Contrary to our hypotheses, the patterns of synchrony from task 5 were more predictable in terms of variations than for task 6.

These results evidenced than more complex and optimized approaches might be necessary to enable the prediction of the lag evolution during our fitness task.

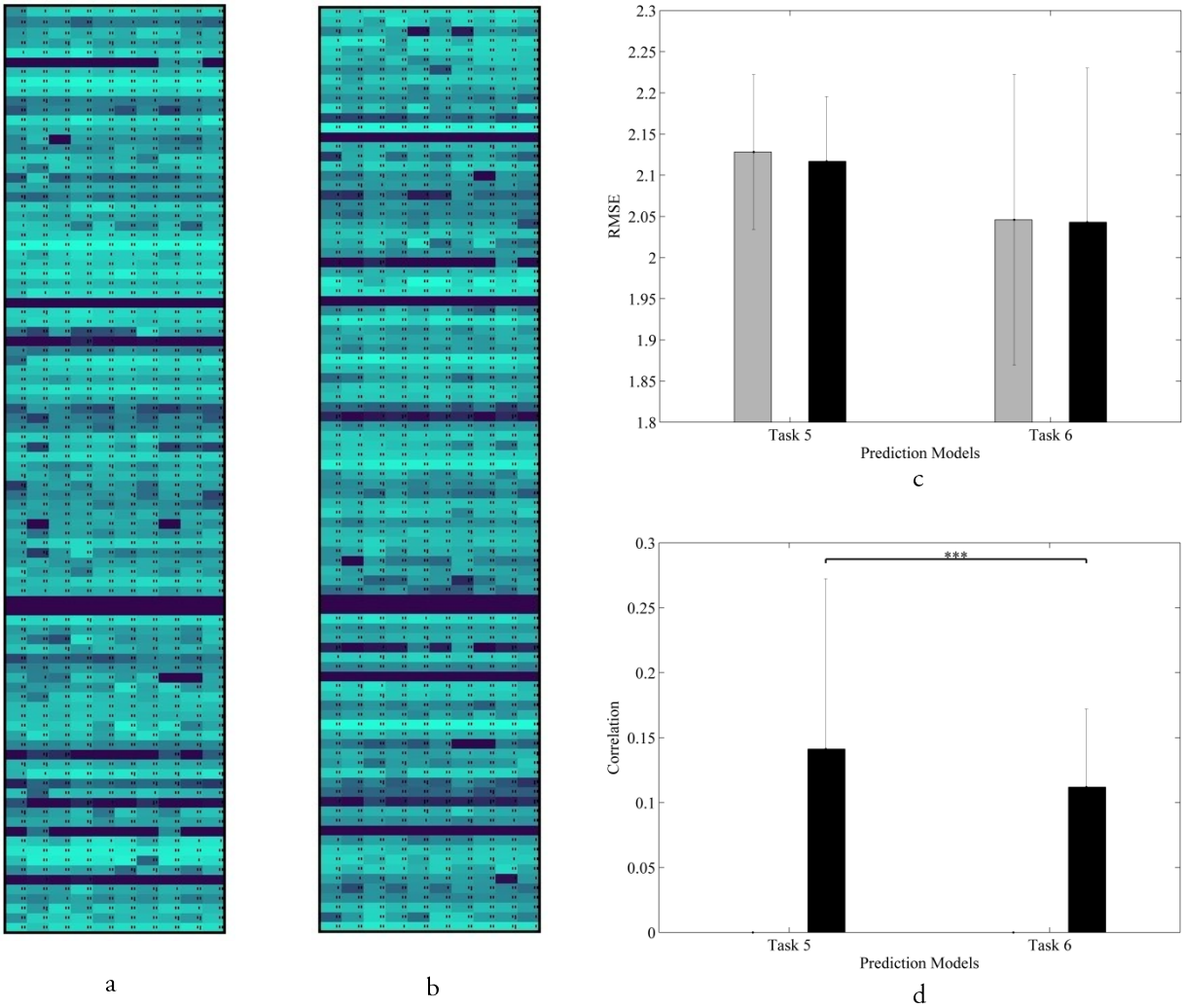

Figure 75: a) & b) ranking of the 96 variables (vertical) for each of the 10 folds (horizontal) for task 5 (a) and task 6 (b), purple is low rank and bright green is high rank c) RMSE for the predictive model in task 5 and 6 and for the fixed model d) correlations for the predictive model in task 5 and 6 and for the fixed model

5.5. Limitations and future works

In this section, we presented the various components of the development of a virtual coach. We proposed to model separately the expressivity of the coach and the interactive model to manage the joint performance of the motion sequence. Both can be data-driven as two motion capture corpus were collected. The same software architecture as for the virtual interviewer was proposed, with the two exceptions that input data are motion capture information and the decision module compute lag predictions. The key aspect of our interactive coach is that its animations depend on the prediction of the lag. This variable includes the information of the relative position of each dyad member within the motion sequence. Based on this information, the motion synthesis model can adjust online the speed of the animation. This minimalist interactive model enables to isolate the essence of the social interaction and to reproduce it to study it in a more controlled way. Thus, both our application (increase the social presence feeling and motivation to perform the motion sequence) and experimental (provide a way to study in a controlled way the synchrony process) aims could be achieved. The first predictive experiment conducted to predict lag was not conclusive and call for more optimized approaches.

Our approach has several limitations which could be addressed in future works. The first is that we did not use individual differences in our modeling approach. As evidenced in our synchrony analysis, individual differences play

a major role in modulating the patterns of synchronization. In addition, each individual has his/her own motion style which is an important individual difference to consider. Together, these dispositions could be used advantageously to improve the lag prediction. In order to bridge the gap between our analysis of synchrony and our prediction approach, a possible step would be to clusterize the synchronization patterns in order to build separate prediction model. The variability in lag patterns being reduced within each cluster, the prediction algorithm should perform better.

The second limitation of our approach resides in our basic prediction approaches. For the development in the near future of optimized prediction algorithms, several non-linear approaches could be investigated and compared as well as models which take into account long terms correlations in the data. In addition, the fact that the motion sequence is composed of predefined, segmented and repeated movements could be used in order to refine the predictive model.

6. SUMMARY AND PERSPECTIVES

As in chapter 4, this chapter presented the analysis of a case study of a social interaction in order to confront our general hypotheses made in chapter 1, 2 and 3. The choice of the fitness task was driven by several arguments. The societal challenge of the lack of daily activity in the population as a major health risk factor led the HCI community and Human Sciences to seriously consider the development of exergames: home video games inducing a physical activity. Although the literature is prolific in both domains, most of the present literature focuses on one-sided interaction with the game, and the avatar when present. The positive role of an embodied entity which provides social support and fosters motivation seems accepted, but research projects consistently overlook the subtle mutual adjustments pervasive to any social interaction, as it was the case for virtual job interviews. To our knowledge, no studies from both domains investigated the importance of synchronization patterns in guided physical activities. This social interaction – a fitness task – is essentially different from the job interview task from chapter 4 for a variety of reasons: it is a more affiliative task where the motion kinematics is the variable of importance. More specifically, the fact that dyad members performed the same predefined motion sequence enabled us to investigate in more details the synchronization patterns and therefore assess more precisely the role of individual differences. Motivated by the idea that low level social interactions are essential to the emergence of more complex social phenomena, this chapter presented a detailed analysis of a fitness coach task.

The fitness task induces the performance of a predefined movement sequence. This highlight the essential role of the kinematics variations often associated with the level of expressivity. The ways the individual performs the motion sequence characterize his/her energy expenditure, but also his/her personal style, mood, attitude, etc. One powerful framework which enables to grasp this expressivity is the system defined by (Laban 1950) which defines a set of movement qualities. Defined as the subjective description of the objective measure of human kinematics often related to its inner dynamics (Runeson and Frykholm 1983), movement qualities have the interesting property to be both experiential and physical, enabling to quantify them and capture more precisely the subjective perception of others' movements. These movement qualities have been shown to be intimately linked to emotions (both expressed and perceived) and less accurately to personality traits. In our specific case of a predefined motion sequence, four were kept throughout the chapter: energy, impulsivity, jerkiness and spatial extent.

In the objective to build a virtual coach, two mains elements are of highest importance: the ability to convey motivation and positive mood through kinematics and the ability to subtly synchronize with the pupil in order to foster the sense of presence and entrain the movement. One main assumption of this chapter was that it would be possible to investigate these two issues separately. Thus, we collected two different motion capture corpus: one with

coaches alone performing the motion sequence under different emotional conditions, and another with coaches and pupils performing the motion sequence together.

The study of the virtual coach expressivity was based on the first corpus. We presented a perceptual study which aimed at studying the impression formed by individuals when watching the same motion sequence with various styles, to identify which kinematics variables were responsible for this impression and to evaluate if these impressions were accurate. Overall, this study provides some insights for the design of our interactive virtual fitness coach. A general positive impression emerged from the perceptual study, this impression mainly based on the impulsivity motion quality. In addition, dominance and agreeableness were the two others perceptual dimensions which could be distinguished from the general impression. In terms of accuracy, observers were partially accurate for emotions but totally wrong for personality traits. Still, both self-reported emotion and personality trait and perceived emotion and personality traits were related to computed movement qualities meaning that information was available to form more accurate judgments. One possibility of this wrong use of available information is that the presentation of only kinematic is too ambiguous. The joint presence of kinematics and other signals such as facial expression or environmental context could help to re-interpret these cues and foster accurate judgments. One future line of research should investigate in which condition these information are adequately used to form accurate judgments. In addition to contribute to the understanding of emotion and personality communication, this study enabled to label our motion capture database with expressivities which could be used to fuel our animation module for the virtual coach. The three identified dimensions – general positivity, agreeableness and dominance – are essential in social interaction. Although we presented some possibilities for the modeling of these expressivities, their actual synthesis and evaluation is outside the scope of this PhD thesis. An interesting future line of research would be to synthesize the essence of each dimension, evaluate if it is correctly perceived and investigate how varying these expressivities affect pupils in a virtual coach training program.

The study of the virtual coach synchrony was based on the second corpus. Within this corpus we focused on three sequential task: the performance of the motion sequence without visual contact (task 4), with visual contact but no instructions to coordinate (task 5) and visual contact and instruction for the pupil to follow the coach (task 6). As in chapter 4, the analysis of the mutual adjustment between the two dyad members was done in two steps: the analysis of the change in bodily signature while facing the other and the interactional synchrony based on cross-lagged-correlation techniques. Both studies evidenced some interpersonal processes with both an influence of individual differences. Globally, it was possible to consider task 5 as a spontaneous synchrony condition inducing more disturbance and energy and task 6 as an intentional synchrony condition inducing more controlled and salient movements to foster a smooth coordination. In terms of individual differences, we investigated the role of three traits from the FFM – agreeableness, extraversion and neuroticism –, affective alexithymia and three empathic traits – personal distress, empathic concern and perspective taking –. A very insightful result from our various analyses is that individual differences do play different role as function of task (spontaneous or intentional) and role (coach or pupil). Thus, agreeableness was not related to any phenomena in task 5 but association with smoother coordination in task 6 for pupils. Hence, this trait might better be characterized by more intentional/high level pro-social motives rather than a spontaneous tendency to look for relatedness. In opposition, perspective taking was strongly related to adaptations and smooth synchronization in the spontaneous condition, in accordance with the famous results from (Chartrand and Bargh 1999). As expected, extraversion was associated with more leadership in the spontaneous condition were uncertainty exist about the leader-follower pattern. This result was true only for coaches. Also in line with our initial hypothesis, alexithymia was associated with bulkier evolution of lag throughout the movement sequence. This pattern appeared only in the intentional task condition. Lastly, personal distress and empathic concern were not associated with any phenomena as the task did not involve any emotional negative content to react on. Altogether these results are highly promising given the tentative nature of some of our hypotheses. In addition, our results are calling for more detailed contextualization of the theory: future research will aim at refining the literature review to identify the specificities of each individual difference and explain the variation we revealed.

To our knowledge, this study of synchronization is the first attempt to characterize the pattern of synchronization in a relatively naturalistic setup. Our encouraging results, particularly in the detailed analysis of the lag evolution, provided a strong ground on which propose the design of a virtual coach. Consistent with the dichotomization done in the previous analyses, we proposed to model separately the expressivity of the virtual coach and the interactive nature of the virtual coach. In this chapter, we focused on the synchronization module operationalized as the online prediction of lag based on motion descriptors from both dyad members. A first and basic prediction experiment showed the feasibility of such model and call for further developments. Future works will attempt to improve this prediction model and evaluate it with pupil following such an interactive virtual coach, compared to a non interactive one.

CHAPTER 6

Conclusions and perspectives

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1. THESIS OBJECTIVES AND METHODOLOGY

Although Virtual Humans (VH) have bodies, current researches suffer from two major limitations which limit the experienced credibility: modeled bodily behaviors lack of social interactivity and do not account for individual differences in terms of full body interaction. Recent developments in human sciences call for a more integrative approach with at its heart the constitutive role of social interaction. Of particular importance is the central and interdisciplinary position of virtual humans in this new research agenda: they are both a way to better investigate the various socially interactive phenomena (VH as experimental tools) and potential solutions for societal challenges (VH as applications).

The main goal of this PhD thesis was to study together full body interactions and individual differences in various social tasks (job interview and fitness coach) toward the proposition of full body interactive virtual humans. Central to this study is the long term objective to develop credible and autonomous virtual humans by combining computer and human scientific knowledge, to generate added value that will prescribe positively future propositions. To limit the scope of the thesis, we focused on body movements (not considering static bodily aspects or other modalities), low level coupling mechanisms and the moderating role of individual differences with the final objective to propose proof of concept of virtual human prototypes (rather than complete functional software). To this end, we undertook a research approach starting from the review and modeling of relevant individual differences in full body interactions to the investigation of their moderating role in two case studies: a job interview and a fitness coach task.

Chapter 2 presented a state of the art in both computer and human sciences about bodily interpersonal processes (e.g., synchrony and empathy) and related individual differences. A set of individual differences was identified whose respective contributions could be added in a model of working hypotheses (HIDID).

Chapter 3 dealt with the empirical validation of this integrative model. Classical personality methodologies were used: after making sure that all assessment tools were "*validated*" in the French language, we administered the selected set of individual differences measures to a large sample population (n = 231). Confirmatory analyses were run to evaluate the goodness of fit of the model and working hypotheses refined.

Chapter 4 presented the job interview case study. In order to analyze "*truly*" interactive behaviors and to be able to build a full body data-driven interactive model for the virtual human, we participated in the collect of a corpus: 31 participants presented themselves in front of 2 judges. Participants behaviors were quantified via video (overall activity) and force plate (postural sway) while judges were video recorded (overall activity). Behaviors were analyzed both at the individual participant level and the interpersonal level. The proposed interactive virtual judge was based on this analysis: its configurations respected the judges' position and behaviors in order to be very close to the corpus and enable the development of data-driven approaches.

Chapter 5 detailed the fitness coach case study. As in chapter 4, our various analyses were based on collected data from two corpuses: the first with coaches performing a predefined movement sequence alone under difference context (n=20) and the second with coach-pupil dyads (n=18) jointly performing the same predefined movement sequence. These two corpuses were collected in order to assess and model separately the coaches' expressivity and interpersonal coordination. In both corpus, kinematics patterns were measured via motion capture systems and quantified using movement qualities as defined in the Laban notation system (Laban 1950). Expressivities in the first corpus were analyzed via a perceptual study in order to identify which kind of kinematics patterns drive positive impressions. For the second corpus, dyad behaviors were analyzed both at the individual and the interpersonal level.

The proposed interactive virtual coach was grounded in this analysis: its defined behaviors are the same as the real coaches in order to be very close to the corpus and enable the development of data-driven approaches.

2. CONTRIBUTIONS SUMMARY

2.1. Working model of individual differences

The review proposed about bodily interaction processes and associated individual differences provides computer scientists with a larger theoretical landscape in order to guide future research about social interaction. More specifically, we highlighted the domain origin of the notion of synchrony and its clearer conceptual definition than behavior matching. The increasing interest of this phenomena (Delaherche et al. 2012) mirrors this better operationalization of the concept. The individual differences identified to be related to these interpersonal phenomena provided a good ground for further investigations of individual different theories. We proposed a theoretical model linking these key concepts both at the level of individual differences (emotion regulation, empathy and pro-social orientation) and the bodily interpersonal processes (patterns of synchrony). Although never mentioned in the literature related to interpersonal process, we discussed the possible associations of the Five Factor model with this theoretical framework. Questioned (and refined) throughout this PhD thesis, these working hypotheses are in themselves contributing to the future of socially interactive virtual humans, both as application and experimental tools.

Given this proposed model, we were able to undertake a confirmatory approach which was the object of chapter 3. This chapter contributes to personality psychology in the integration of different individual differences concept originally not related. Dispositions in emotion regulation were associated to self-concepts in (Konrath et al. 2011) and to empathy in (Grynberg et al. 2010), but our proposed approach is the first path model proposed linking the three aspects. The validity of the goodness of fit found with our data associated with the soundness of the underlying theoretical model provide a good ground to explore in more details this nomological framework. Being able to locate each individual difference relatively to each other is of primary importance for two reasons: it enables to integrate findings from various studies using one of these individual differences alone, it gives some information about the organization and structure of dispositional processes, and some information about their respective contributions in social tasks. As explained in (Wright 2011), such a structured process view of personality could have more explanatory power than descriptive model such as the Five Factor model of personality, particularly against variability in tasks and states. About the confirmatory study, of particular importance is the replication of the model on a different more mature sample and the use of alternative individual differences assessment tools.

The large majority of the individual differences investigated in the literature and present in our model (emotion regulation, empathy and pro-social orientation) are evaluated via self-report questionnaires. Although they are systematically validated against alternative measures supposedly less biased, they stay high level in nature as their scores represent the reflexive evaluation by an individual of how he/she behaves in general. In chapter 2 and 3, we attempted to bring closer these identified individual differences to low level perceptual processes by investigating the cognitive style of Field Independence Dependence (FID). The choice of this concept was guided by old (Witkin and Goodenough 1977) and recent (van Baaren et al. 2004) findings about the role of FID in the interpersonal domain. However, a critical literature review of the evolution of the concept and findings from various topics revealed high inconsistencies in underlying hypotheses and measurement methods. We followed the argumentation that two different construct embedded in the two measures of FID could explain these discrepancies: the Embedded Figure Test based FID being closer to fluid intelligence and Rod and Frame Test based FID being closer to a perceptual style (i.e., frame of reference preference). In this line, the RFT based FID appears a promising root to explain individual differences in the agentic domain. Although new analyses are required to better confirm this approach, this

clarified description of the FID construct might be a contribution in itself. Future works will attempt to further investigate this model.

2.2. Toward a bodily interactive virtual judge

Researches on the job interview scenario generated several analysis directions and contributions. To respect the ecology of the corpus and capture subtle bodily reactions of the participants, we undertook to measure and analyze postural sway following posturology methodologies based on force plates. Force plates provide highly valuable information about bodily reaction such as affective reactions (Horslen and Carpenter 2011) and interpersonal coordination (Varlet et al. 2011). The detailed methodology and analysis of such nonverbal signals provide computer scientists with a new non-invasive apparatus for the study of various engaging situations. In addition, we evidenced the complementarities of such an analysis compared to video based variables: gross movement are captured by the video but more subtle movement related to postural stiffness and rapid reaction are present only in force plate signals (Giraud et al. 2013).

In the perspective of a virtual judge application for job interview training programs, we proposed an analysis of the tasks performance conceptualized as perceived discomfort and motivation. Being able to automatically predict these perceptions would be an essential module to provide feedbacks in a job interview application. In our study, we highlighted how postural variables are more related to discomfort and global movement activity to motivation. The resulting prediction was encouraging given the simplicity of the approach. Going more multimodal (i.e., including facial expressions and prosody) and refining the task performance evaluation (i.e., rating the different nonverbal modality separately) is the next step toward a robust automatic prediction module. Together, these results contribute to the development of job interview and more generally public speaking application developments.

Our analysis of bodily interpersonal processes in the job interview corpus has been possible thanks to the characterization of judges' behaviors: as judges were found to have bodily behaviors in a segmented fashion (long periods without movements), a semi-automatic segmentation of judges postural moves was presented. Based on this segmentation, we looked at how participants' behaviors were related to judges' postural moves both in behavioral changes and interpersonal coordination. In both cases, interpersonal influences were revealed. In addition, these results were found only with the analysis of segmented behaviors, confirming the relevance of our approach. Lastly, synchrony was analyzed at a multimodal level (postural and global movements of the participant correlated with judges' global activity) via canonical correlation which evidenced large individual differences in the preferred synchronized channel. Future works could investigate these potential "*interactional style*". To our knowledge, this is the first study to provide such an analysis, spontaneous interpersonal processes being studied almost exclusively in affiliative scenario. These methodological points and results make clear the relevance of studying bodily interpersonal processes not only in collaborative situations. They open new research perspectives on the study and modeling of job interviews.

The investigation of how individual differences modulate these interpersonal processes was also hypothesized to be a key factor in the interactive domain of job interviews. In this corpus, extraversion, neuroticism, agreeableness and affective alexithymia were investigated. All showed some tendencies to correlate with bodily interpersonal influences. In the interpretation of our results, we had to consider the strong emotional context as it interferes between individual differences and our initial "non emotional" hypotheses. The situation induces a potential ego-threat which can induce negative emotions which induce impaired interpersonal coordination (due to less spontaneous and more controlled behaviors). Quickly summarized, agreeableness was not of real importance (expected given the non-affiliative context), alexithymia and neuroticism were both related to freezing related behaviors but with different patterns of synchronization (high neuroticism impair spontaneous synchrony whereas alexithymia induce postural

lag) and extraversion was related to less ample and stiff postural movements and more lagged synchronization (interpreted as an enhanced distance from the situation, a tendency to not be affected directly by the context). The results were partially in line with our expectations, but the interplay of individual differences and affective context influences on interpersonal processes limit the interpretability of the results. Together these results evidence the importance to consider individual differences in such a scenario and confirm the relevance of our selection. Further investigations need to challenge subjects as increasing task difficulties could reveal protective and vulnerabibilty factors (coping strategies) associated to each individual differences.

Lastly, the precedent analyses provided us with a solid ground to define the architecture of a virtual judge close enough from the collected corpus to embed a data-driven interactive model. We described the various functional elements and highlighted the key module of the virtual judge: the prediction of the postural moves timing as a function of participants' behaviors. A first prediction algorithm showed to perform better than random providing a good starting point to its optimization (articulating both behavioral and psychological individual differences and developing the algorithm). As such, the contribution of this part is more conceptual but near future developments promise to deeply contribute to both computer and human sciences.

2.3. Toward an interactive virtual coach

The study of our fitness coach task also generated contributions on several levels. As the task is the performance of a predefined movement sequence, we needed to quantify the expressivity quantified via kinematic patterns. To this end, movement qualities were argued to be an interesting concept potentially bridging the gap between movement objective quantification and subjective perception. Our first contribution was to investigate the validity of this assumption by comparing on motion captured data one computation of movement qualities and their perceptions. Our results revealed partial associations between the two, energy and impulsivity being accurately assessed (as one dimension), expansiveness being weakly accurate and smoothness showing no associations between quantified and perceived. These results add to the tenuous literature about the evaluation of motion qualities quantifications. Future works could investigate in a more systematic manner various possible quantifications of movement qualities against their perceptions.

In addition to the evaluation of perceived movement qualities, we investigated the perception of personality and emotions through these kinematics patterns. Results revealed high inter-rater agreements and the presence of a general positive expressivity halo explaining the variance on most of the dimensions. Both self-reported and perceived personality traits and emotions were related to movement qualities, but without clear accuracy (partial accuracy was found for emotions) as in the existing literature. These results evidence that kinematics do embed information but are too ambiguous to be used solely: context or other modalities could jointly help disambiguate the expressions. Another valuable finding is that the perceptual realm of movement expressivity in this fitness task is mainly composed of three dimensions: general positive expressivity (mainly driven by movement impulsivity), perceived agreeableness and perceived dominance. Interestingly, these three dimensions are relevant for the design of a virtual coach: all three can be used to adapt the virtual coach style to user preferences (e.g., a more dominant coach for a less dominant pupil). Together, these analyses at the individual level based on movement qualities contribute to the development of more complete perceptual studies within the framework proposed in (Scherer 2013).

The interpersonal analysis was based on a second corpus. We focused on three task: task 4 were the coach and the pupil perform the predefined motion sequence back to back, task 5 where they perform the motion sequence face to face without instruction to coordinate, and task 6 where they perform the motion sequence face to face with the instruction that the pupil should follow the coach. Task 4 acts as a control condition and task 5 and task 6 enable to study interpersonal processes in two different conditions: spontaneous and intentional. As in the previous case study,

we analyzed the interpersonal processes both in expressivity changes and interpersonal coordination. Significant differences in expressivities appeared coherently between task 4 and 5 (more energetic and jerky movements cause by the visual interference of the other) and between task 5 and 6 (more controlled and salient movements caused by the intentional coordination process). Synchrony was computed based on the energy movement quality (more related to timing). This global synchrony emerged significantly greater than task 4 in both task 5 and task 6, the difference in magnitude between task 5 and 6 being relatively small compared to task 4. Together, these results add to the literature on spontaneous and intentional joint movements: spontaneous coordination can emerge as strongly as intentional ones but their patterns are different.

To analyze the moderating role of individual differences, we develop further the concept of synchrony pattern by implementing a peak picking algorithm in order to follow the evolution of lag (of pupils related to coaches) in the motion sequence. The same individual differences as in chapter 4 (extraversion, neuroticism, agreeableness and affective alexithymia) and three empathy related disposition (personal distress, empathic concern and perspective taking) were assessed in the second corpus. Using correlations and multiple regressions, we investigated how individual differences were related to synchrony, computing the results separately for task 5 and task 6, as well as for coaches and pupils. A first revealing result is the fact that all significant associations occurred in only one specific context: either in task 5 or 6 and either for coaches or pupils. This finding advocates for a more contextual interpretation of individual differences. As these contextual influences were not taken into account in the hypotheses defined at the beginning of the PhD thesis, interpretation were not straightforward but still insightful. While personal distress and empathic concern showed no association (as no emotional event to react on is present in the corpus), extraversion and perspective taking were strongly associated with synchrony patterns in the spontaneous condition and agreeableness, alexithymia and neuroticism in the intentional condition only. Spontaneously, extrovert coaches took more the lead and high perspective taking pupils let more the lead to coaches. This effect of perspective taking was enhance by the interaction between coaches and pupil perspective taking, with a multiple regression explaining 60% of overall lag in task 5. This is interpreted as a spontaneous adaptation pattern between coach and pupils to less interfere in the movement sequence performance. For task 6, more agreeable coaches intentionally reduced their variability and agreeable pupil let coaches take more the lead. This pattern is a perfect example of how agreeableness is conceptually related to smoother interaction but differentially related to behavioral variables given specific contexts (here depending on being a coach or a pupil). Lastly, neuroticism and alexithymia showed the same result of increasing lag variability for pupils, a sign of a more disturbed synchronization pattern. This result is in line with the idea that worst emotion regulation is related to impaired interpersonal coordination. The exact explanation of why this effect occurred only in the intentional condition needs further investigations. Overall, these analyses and results confirmed three points: individual differences are essential to the understanding of both spontaneous and intentional joint movements, the computation of synchronization pattern related variables is highly valuable to investigate the quality of the coordination and the context of both task and role are highly discriminative in how individual differences are related to bodily coordination. From this base, many lines of researches appear promising both in the field of sport tasks and more broadly in coordinative tasks.

As in the precedent chapter, we built on these various results to define the architecture of a virtual coach close enough from the collected corpus to embed a data-driven interactive model. We described the various functional elements and highlighted the key module of the virtual coach: the prediction of lag evolution as a function of participants' behaviors. A first prediction algorithm was proposed but the performance was not above chance. Given the high potential of this virtual coach, future works will undertake a more complete approach: optimizing the algorithm by taking advantage of the recurrent structure of the movement sequence and use the high explanatory power of individual differences for synchrony patterns. As such, the contribution of this part is more conceptual but near future developments promise to deeply contribute to both computer and human sciences.

3. DISCUSSION AND PERSPECTIVES

3.1. Individual differences grounded in bodily processes

This PhD thesis began with an attempt to relate various individual differences in empathy, emotion regulation and pro-social orientation within a nomological framework. This approach echoed the call for a more process based personality in opposition to the hegemony of descriptive approaches such as the Five Factor model of personality (Wright 2011). Still, FFM traits are useful, but they should be reconsidered theoretically as done by (Graziano et al. 2007) with the trait agreeableness. Today, various approaches attempt to explain individual differences in motivations and behaviors with a surprisingly consistent two factor meta-structure of agency and communion at the heart. However, to our knowledge no clear consensus exists about a common way to operationalize and evaluate these dimensions. In the near future, personality psychology might propose an interesting integrative move to account for these cross theory consistencies at the image of (Luyten and Blatt 2011). Such a more dynamic approach to personality is a promising route for Human Computer Interaction and Virtual Human as it is in better position to explain contextual effects and interpersonal behaviors.

Another promising route to link individual differences and variations of interpersonal behaviors within tasks is to consider the gap which exists between self-report measures and perceptual/behavioral tests. In this PhD thesis, we provided a first attempt by investigating the perceptual style of Field Independence Dependence (FID) without success. This discrepancy can be attributed to several limitations which provide interesting future directions. First of all, perceptual test are often near to ability test which are often related to general or fluid intelligence. This methodological issue is combined with the fact that it is a challenge to isolate a perceptual phenomenon: all low level mechanisms tend to be inter-related. As an example, the Rod and Frame Test is interesting for revealing differences in visuo-vestibular conflicts, but this effect is confounded with the impact of fluid intelligence in RFT scores, as well as other general abilities (e.g., spatial abilities) or styles (e.g., impulsivity). The development of less biased tests is a promising future direction. Also, perceptual tests assess how an individual interact with the environment (e.g., for the RFT, how an individual a priori processes multisensory information and selects spatial frames of reference) in a specific context whereas self-report measures assess how an individual think he/she behaves in general. The link between self-report and bodily processes could be further investigated by considering the influence of tasks. This is the person x situation approach to personality developed for example for the understanding of agreeableness and how it provokes pro-social behaviors (Graziano et al. 2007). The evidenced associations between self-reported measures and general orientations are sometimes mediated by situational effects: (Bresin and Robinson 2014) showed that agreeableness is related to subjective well being partly via situation selection (positively valenced) rather than solely emotion regulation. Here again, a process theorization of the self-reported trait would enable to define typical task where individual differences emerge. A research question is whether these high level self-report measures covariate with lower level individual differences.

At the center of these two future directions seems to be the concept of agency. In this PhD thesis we conceptualized FID as a measure of agency, field independent individuals (ie., relying more heavily on proprioceptive relationships) having an enhanced agentic self. However, no associations where found neither with self-construal independence or perspective taking. This result echoes the difficulty researchers have to found associations between spatial perspective taking abilities and social self-reported perspective taking. However, recent researches push toward the concept of a self anchored in the perceptual body, and more specifically via the vestibular system (Ferre, Lopez, and Haggard 2014). Spatial cognition, body representation and affective processes appear to be affect by this meta-sense which is also related to postural control and other visuo-motor processes (Mast et al. 2014). Individual differences in agency and prosocial orientation might be better understood by articulating this concept of bodily grounded agency and the

various self-report scales of autonomy/agency. Also, moving toward a more relational definition of agency might help to bridge this gap between the sensori-motor and the social. The definition of agency and perspective taking developed by (Gillespie 2012) is already going into this direction, but better person x situation conceptualization could foster the articulation and enhance the development of more task oriented self-report scales.

The same approach could be undertaken for the concept of emotion regulation. Emotion regulation is investigated via self-report scales but perceptual tests can also assess specific emotion regulation abilities. As we discussed in this PhD thesis, empathy and emotion regulation appear to be the interplay of several additive mechanisms, each related with specific emotion regulation characteristic. For example, the lowest level is emotion discrimination and is related to affective alexithymia. In the perceptual domain, this construct is related to visceral perception and has been technically operationalize as the ability to discriminate one's own heart bit (Craig 2002). The perceptual test has been showed to be related to alexithymia (Herbert, Herbert, and Pollatos 2011) which provide some convergent validity of the self-report scale. However, the moderate correlations between the two (only 8% explained in a multiple regression) also advocate for a more detailed analysis of these discrepancies. All the issues highlighted about FID are also at play in the development of such tests. Future researches should be attentive to these tests developments and how they will make evolved our understanding of the social self.

3.2. Bodies are more than communicative channels

The two case studies investigated in this PhD thesis were different in terms of nonverbal behaviors at play. We systematically focused on the measure of full body variables of movement. In the job interview, in addition to classical video based global movement extraction, we captured and calculated postural sway features which are considered as global indicators of the individual stance. These signals are dynamical description of the posture (instead of static descriptions). In the fitness coach task, we extracted movement qualities from the kinematic patterns of the motion sequences. What postural sway and movement qualities have in common? Beside the fact that both are continuous and body related variables, they are inherently related to the inner dynamic of the individual, both in terms of affective states and action possibilities. More than just influenced by affective states, they are involved in the circular causality of embodiment: social phenomena influence bodily behaviors which influence social phenomena (Laird and Lacasse 2014)(Fuchs and Koch 2014). The phenomenon of embodiment is particularly salient in the study of emotions. In one direction feeling of emotions requires the participation of somatosensory cortices (Damasio et al. 2000), modulates muscle contraction (Coombes, Cauraugh, and Janelle 2006) and are associated with schematic representations of upward and downward motion (Casasanto and Dijkstra 2010). And in this other direction body postures have been found to modulate felt emotions (Duclos et al. 1989), arm flexion being related to attitudinal changes (Cacioppo, Priester, and Berntson 1993) and a variety of other body related variables (Niedenthal et al. 2005). More recently, postural movements via the framework of approach avoidance theory (Harmon-Jones, Gable, and Price 2011) and movement qualities have also been shown to influence and be influenced by emotions (Koch 2014)(Koch, Fuchs, and Summa 2014). Overall, it appears probable that it is better to not strictly distinguish the moving body and the inner dynamic states (either they are emotions, attitudes or other phenomena) and rather highlight the congruency of their qualitative dynamics (Sheets-Johnstone 1999). Considering these aspects when modeling virtual humans could enhance their embodiment realism.

A promising route to further explore the potential of these kinds of bodily variables is the notion of affordance. Originally proposed by (Gibson 1950) to account for the direct perception of action possibilities in the word (Weast et al. 2014), recent use of the notion enlarge the concept in an attempt to include affective and social phenomena: for example (Fuchs and Koch 2014) apply it to emotions: "*Referring to Gibson's (1979) concept of affordances (that means, offerings in the environment that are available to animals, such as a tree being "climbable," water "drinkable," etc.), one could also speak of affective affordances: things appear to us as "important," "worthwhile," "attractive,"*

"repulsive," "expressive," and so on. Without emotions, the world would be without meaning or significance; nothing would attract or repel us and motivate us to act". With postural dynamic and movement qualities being intimately linked to individuals' inner states, the individual externalizes his/her readiness to interact in motor terms. Whether or not the concept of affordance is relevant in social context is an ongoing debate (Zebrowitz and Collins 1997). Overall, this discussion echoes the discussion of the previous section about the role of the vestibular system in "anchoring the self". The future development of these converging lines of research is a promising route to the understanding of full body interpersonal coordination but also for the modeling of more integrative and coherent virtual humans.

Behavior matching has been a central concept in the understanding of how humans spontaneously attune to each other. Coined a social glue, its automaticity has been proven and various studies highlighted moderators which were used in this PhD thesis. However, this notion appears to be poorly defined operationally. In opposition, the notion of synchrony gained increasing interests with a developing methodological framework. Considering the human body and its dynamic as the core element of various social phenomena favors this last conceptualization of social tuning and adaptation. Some recent works even proposed that behavior matching might emerge from synchrony patterns (Lenay and Stewart 2012). The study of how synchrony might encompass and generate mimicry in naturalistic settings is a future work to follow. Also, one interesting property of synchrony is that its focus is on time rather than modality matching. In our job interview task, participants showed various patterns of synchronization revealing differences in synchronized modality preference. Thus, the synchrony concept might help to overcome the sharp delineation of nonverbal modalities to better focus on underlying processes of social tuning. The integration of other modalities such as gaze and proxemics in the synchrony framework could bring new insights into interpersonal adaptation patterns.

3.3. Coupling corpus data analyses and virtual human modeling

In chapter 4 and chapter 5, we undertook the detailed analysis of dyadic data before proposing full body interactive model of virtual humans. The main advantage of our approach was to be able to base our interactive model on dyadic data. Such data driven approach is essential to capture the subtle interpersonal dynamics of social interactions. Most of the current literature in Virtual Human bases their interactive behaviors on heuristics or high level inference model (i.e., theory of mind). Although these approaches ensure proximity with some a priori theoretical frameworks, they miss the subtle influence of bodies on each other. Of particular importance is the timing of these behaviors rather than the channel similarity (interactional synchrony versus behavior matching). The backchannel modeling literature undertook such a data driven approach and provide a solid ground to model data driven interactive behaviors (Morency, Kok, and Gratch 2010). Some very recent works propose the prediction of full body movements based on dyadic corpora (Yang, Metallinou, and Narayanan 2014). Additionally, these data-driven approaches are never totally theoretically free: focusing on multimodal synchrony is a theoretical choice and some specific algorithm tuning can be driven by theoretical sound elements. For example, the time window of analysis can be derived from a cross-lagged correlation approach with a discussion about the appropriate sensitivity/reliability ratio of the analysis.

In addition, the collected dyadic data can be used to enhance the understanding of human interpersonal behaviors in a Human Sciences perspective. Undertaking the objective that the collected corpora could benefit both computer and human sciences could constrain positively the analysis. A human science perspective will attempt to limit the social phenomena at play in the corpus in order to better isolate relevant variables of interest. This strategy can alternatively reduce the ecological validity of the corpus. Conversely, computer scientists will attempt to fit a realistic task in order to propose models with potential application driven goals. At the analysis level, the descriptive analysis of the corpus provide a first view on how data are organized and related, and as for the choice of the time window could give some

guidelines for the design of a predictive model. Conversely, when building a predictive model, scientists provide an alternative perspective on the corpus. Together, these back and forth between these two perspectives can lead to the design of a parsimonious yet relevant virtual human model. This approach could be undertaken more systematically, especially in the design of full body interactive virtual humans where human sciences need virtual humans as experimental tools to re-enact social interaction (based on real data).

One challenge of such an approach is to convert descriptive findings into specifications for the predictive algorithm. In this PhD thesis, this aspect was salient with the difficulty we had to integrate our descriptive findings of how individual differences were related to interpersonal behaviors into the proposed description models. In the literature of backchannel, some authors attempted to model individual differences but with a data driven approach (de Kok, Heylen, and Morency 2013). In the specific case of individual differences, one possibility is to constitute groups of individuals and build specific models for these typical more homogeneous populations. However the clustering approach is not very popular in personality psychology as it erases subtle variations between individuals. If we conceptualize our predictive problem as a regression problem, an alternative possibility is to associate individual differences random intercepts and slopes which act as moderators. Future research will investigate different strategies to advantageously account for these individualities and improve the prediction algorithm.

4. GENERAL CONCLUSION

This PhD thesis aimed at investigating together individual differences and full body interpersonal processes in the attempt to propose full body interactive virtual humans. Our research approach made benefit of the growing literature on full body social interaction in human sciences and individual differences to propose a general model of working hypotheses. Throughout the chapter of the manuscript, this model was refined but proved to be valuable in the interpretation of experimental results. Identified individual differences were found to be related in a coherent nomological framework, in two cases studies the participants showed full body interpersonal coupling and in both cases identified individual differences played some moderating roles. From these analyses, two interactive virtual human models were proposed which have the potential to be valuable for both computer and human sciences. Future works will further develop these models and evaluate them in interactive scenarii.

PUBLICATIONS

Published and in preparation

1. PUBLISHED

Authors:	**T. Giraud**, M. Soury, J. Hua, A. Delaborde, M. Tahon, D.A. Gómez Jáuregui, V. Eyharabide, E. Filaire, C.Le Scanff, L. Devillers, B. Isableu, J.C. Martin.
Title:	Multimodal Expressions of Stress during a Public Speaking Task
Content:	Corpus description from chapter 4
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Authors:	**T. Giraud**, D.A. Gomez, J. Hua, B. Isableu, E. Filaire, C. Le Scanff and J.C. Martin
Title:	Assessing Postural Control for Affect Recognition using Video and Force Plates.
Content:	Comparison of COG extracted from video and force plates
Conference:	ACII'13 (poster)

Authors:	F. Focone, **T. Giraud**, V. Demulier, J.C Martin, C. Le Scanff, B. Isableu
Title:	Evaluation d'un outil low-cost pour le recueil de données cinématiques par l'analyse fréquentielle du signal de l'articulation du genou.
Content:	Qualitative analysis of kinect data in the fitness corpus
Conference:	ACAPS'13 (poster)

Authors:	**T. Giraud**, F. Focone, V. Demulier, C. B. Isableu, J.C Martin
Title:	A protocol for studying the impact of positive vs. negative emotions on a predefined sequence of full-body movements.
Content:	Validation of the protocol to elicit emotions in the first corpus of chapter 5
Conference:	CERE 2014 (communication)

Authors:	**T. Giraud**, F. Focone, C. B. Isableu, J.C Martin, V. Demulier
Title:	Toward an Expressive Virtual Coach: Fitness Movements in Emotional and Motivational Contexts.
Content:	Validation of the protocol to elicit emotions in the first corpus of chapter 5
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2. SUBMITTED

Authors:	D. Gibas , **T. Giraud** , J. Le Conte , L. Rubens , J.C. Martin , B. Isableu
Title:	An attempt to validate the Self-Cosntrual Scale: systematic approach and model limitations
Content:	Validation of the self-construal scale
Journal:	European Review of Applied Psychology

Authors:	**T. Giraud**, F. Focone, V. Demulier, C. B. Isableu, J.C Martin
Title:	Emotion and personality perception through full body movement qualities: a sport coach case study.
Content:	Perceptual analysis presented in chapter 5
Conference:	Transactions on Applied Perceptions

Authors: F. Focone, **T. Giraud**, V. Demulier, J.C Martin, C. B. Isableu
Title: Impact of mood induction on movement expressivity during a fitness task.
Content: Impact of the four conditions in the first corpus (results not presented in this thesis)
Conference: Journal of Nonverbal Behaviors

3. IN PREPARATION

Authors: **T. Giraud**, D. Gibas , C.Le Scanff, B. Isableu, and J.C. Martin
Title: Relating dispositions in empathy, alexithymia and self-construal: a path analysis
Type: Journal of psychology

Authors: **T. Giraud**, D.A. Gomez, B. Isableu, and J.C. Martin
Title: Job interviews as social interactions: synchrony and individual differences in a non affiliative context
Type: Journal of psychology

Authors: F. Focone, **T. Giraud**, V. Demulier, J.C Martin, C. B. Isableu
Title: Evolution of expressivity, predictability and synchrony across the fitness task.
Type: Journal of psychology

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