Interrelation between the sensorimotor and emotional components of social space: behavioral and psychophysiological evidence

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THESE

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INTERRELATION BETWEEN THE SENSORIMOTOR AND EMOTIONAL COMPONENTS OF SOCIAL SPACE: BEHAVIORAL AND PSYCHOPHYSIOLOGICAL EVIDENCE

INTERRELATION ENTRE LES COMPOSANTES SENSORIMOTRICES ET EMOTIONNELLES DE L'ESPACE SOCIAL : CONTRIBUTIONS COMPORTEMENTALES ET PSYCHOPHYSIOLOGIQUES

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« Et un lion, ça fait transpirer de combien de gouttes ? »

Chouquet, 6 ans

« Et un chat ? »

Chouquette, 4 ans

ABSTRACT

The distance individuals maintain between themselves in social context (interpersonal distance) is of paramount importance as it contributes to the quality of the social interaction. Too large interpersonal distance is not conducive to social interaction whereas too short interpersonal distance triggers discomfort and favors (physiological and behavioral) defensive reactions. Interpersonal distance seems thus built on motor/functional representation of visual space, with a prevalent role of near body action space (i.e., the peripersonal space), but seems to depend also on social factors. Therefore, interpersonal distance adjustment may rely on a subtle balance between the need to interact efficiently with others and the need to maintain a margin of safety protecting from potential hazard including others. As a result, interpersonal distance increases with threatening individuals and decreases with attractive ones, which depends on others' emotional state that can be determined from their facial expression. However, valence evaluation of facial expression, irrespective of the emotion, is not absolute and depends also on the emotional context.

In this context, the aim of the present thesis was twofold: (1) to qualify the link between interpersonal distance and the physiological response triggered by individuals within the peripersonal space with varying degrees of threat; (2) to quantify the effect of emotional context on interpersonal distance adjustment. Using a virtual reality environment, known to favor immersion and "authentic" physiological and behavioral responses, we highlighted a linear relation between physiological response and interpersonal distance adjustment. Moreover, our data revealed that contrast effect induced by emotional context on valence judgment (shift toward the opposite direction of that of the context) also subtly altered interpersonal distance adjustment.

Overall, the present thesis suggests that interpersonal distance adjustment depends both on the representation of peripersonal space and the emotional context. Our data support that interpersonal distance adjustment refers to the need for homeostasis during social interaction in relation with the defensive value of the peripersonal space. This distance maintained with others, necessary to ensure homeostasis, can indeed be quantified from the physiological response triggered by others within the peripersonal space. Beyond providing new insights on the link between peripersonal space representation, emotional processing and interpersonal distances, the present thesis provides a new theoretical framework that could be relevant for clinical investigations, taking into account in particular sensitivity to interoceptive information.

Keywords: Interpersonal distance – Threat; Physiological response – Peripersonal space – Emotional facial expression – Emotional context – EDA

PUBLICATIONS

Publications related to the PhD thesis

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Cartaud, A., Ruggiero, G., Ott, L., Iachini, T., & Coello, Y. (2018). Physiological response to facial expressions in peripersonal space determines interpersonal distance in a social interaction context. *Frontiers in Psychology*, 9, 657. 10.3389/fpsyg.2018.00657

Other publications

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FIGURES

TABLES

ABBREVIATIONS

ANS	Autonomic nervous system
CAM	Category adjustment model
CS	Conditioned stimulus
EC	Evaluative conditioning
EDA	Electrodermal activity
FE	Facial expression
HF-HRV	High frequency heart rate variability
IPD	Interpersonal distance
PLD	Point-light display
PLW	Point-light walker
PPS	Peripersonal space
RF	Range-Frequency
SC	Skin conductance
SNS	Sympathetic nervous system
US	Unconditioned stimulus
VR	Virtual reality

General

e.g.	Exempli gratia
i.e.	Id est
vs	versus

INTRODUCTION

I. THE SPACE AROUND US

Although no visible boundaries segment the space we move in, our representation of the visual space is not a boundless three-dimensional continuum. Our brain represents differently the space depending on our ability to physically interact with the objects of our environment. Thus, this functional division of space is implicit and is dependent on our actions on the environment. Finer divisions of spatial representation exist (e.g., Previc, 1998), but for the purposes of this thesis, we will only consider two main functional subspaces of the visual space whose reference frame is based on the whole body: the space of what is at hand called the *peripersonal space* by Rizzolatti et al. (1981) (hereafter PPS) and the space of what is not: the *extrapersonal space* (Holmes & Spence, 2004; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997; Serino, 2019). Thus, the concept of motor action (what is reachable, at hand vs what needs a whole body-displacement to be reached) is at the core of this theoretical framework of spatial representation to determine the boundary between the PPS and the extrapersonal space.

In this section, we will focus on the PPS, which can be seen as an abstract interface between the body and objects, allowing us to interact with them (Serino, 2019), and how its representation can vary. Indeed, due to its functional aspect, the representation of PPS is sensitive to our motor capacities, but also to the affective value of the stimuli we intent to interact with and to the presence of others (Fig. 1).

Moreover, if we focus on social interaction, the distance maintained between individuals interacting (interpersonal distance) also seems to refer to some extent to motor and affective metrics. Therefore, we will also focus on interpersonal distance and on questioning the extent to which this distance is linked to PPS representation.

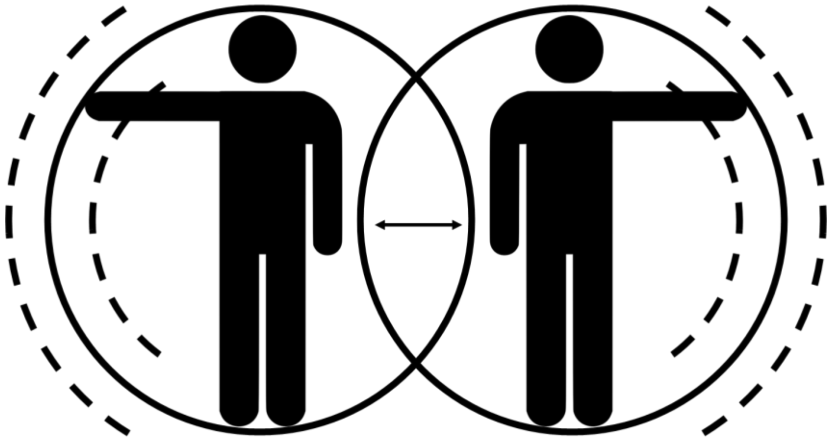

Fig. 1. Schematic illustration of PPS (within the solid circle) and the extrapersonal space (outside the solid circle). PPS representation (dashed curves) can vary depending on motor capacities and on the affective value of the stimulus to interact with. The double arrow represents the interpersonal distance whose adjustment is also dependent on the motor capacities and the affective dimension of the interactant.

I.1. An action space

The idea that the perception of the world around us is rooted in our motor experiences has been highlighted in particular by studies focusing on the ability to visually and physically explore it. In the well-known study of Held and Hein (1963), kittens raised in the dark could move around in a lit scene for a few minutes a day in a carousel. In the lit scene, both equally visually explored the scene, but while one of the kittens of a pair was actively walking into the scene, the other one was passively carried in a gondola, dragged by the physical exploration of the first one. Results showed that, while the active kitten had adapted reaction to looming stimuli and normally avoided bumping into hazards or falling off a cliff when walking in a free condition; that was not the case for the passive kitten. Despite the same motor experience in darkness and the same visual experience in the carousel, only the active kitten showed normal visuo-motor behavior. This suggests that the way we perceive and represent our three-dimensional visual space is dependent on both our motor abilities and the possibility to match motor activity with sensory consequences. Therefore, even if congenitally blind individuals can mentally manipulate spatial information relating to tactile or auditory stimuli, they are less accurate than sighted individuals when the task requires processing complex spatial information (Gandhi, Ganesh, & Sinha, 2014; Vecchi, Tinti, & Cornoldi, 2004). For example, blind individuals show difficulty in mentally imagining spatial places from a different perspective that the one they are used to (Byrne & Salter, 1983). Furthermore, when congenitally blind individuals can recover sight following eye surgery, they show deficits in the visual recognition of objects explored haptically, but with clear improvements within a few days after the sight-recovery surgery (Held et al., 2011). Taken together, these results suggest that cross-modal interaction with our environment is necessary to represent it three-dimensionally. Furthermore, as a consequence of the functional characteristics of the visual space, motor coding of an object is strengthened by its proximity (Wamain, Gabrielli, & Coello, 2016). Space is therefore interconnected with our action system. Overall, the visual space is segmented into a space in which we can act *hic et nunc*, built on our motor representations, and a space in which we cannot act directly but potentially in the future.

How to test PPS representation

Before going any further, it seems necessary to describe the main tasks used to measure the PPS representation (non-exhaustive, Fig. 2):

- *Reachability judgment tasks* are based on psychophysical methods. Participants have to estimate whether they can reach or not an object displayed at different distances from them without performing the reaching movement (Coello, Bourgeois, & Iachini, 2012). The boundary of PPS is established using logistic regression that computes the subjective equalization point, i.e., the distance at which the participant responds randomly (shift in the binary reachable/not reachable response; later developed in the general method section). This technic evaluates the representation of the reaching space.

- Another method to define the PPS boundaries uses *multisensory integration tasks* during which a sensorial stimulus irrelevant for the task (i.e., a sound) approaches the participants during a tactile detection task (Serino, 2019). Reaction time to detect the tactile stimuli diminishes when the sensorial stimulus is located within the PPS, a convenient proxy to determine the boundary of PPS. This way, the multisensory representation of PPS is measured.

- A third method uses *line bisection tasks* during which participants mark the mid-point of a line presented at different distances. A leftward bias is usually observed when righthanded participants bisect lines in the PPS whereas a rightward bias is observed when they bisect lines in the extrapersonal space (e.g., using a laser pen). PPS boundaries can be defined on the basis of this progressive shift (Varnava, Mccarthy, & Beaumont, 2002). PPS boundaries are thus evaluated via the change in the side of attentional bias.

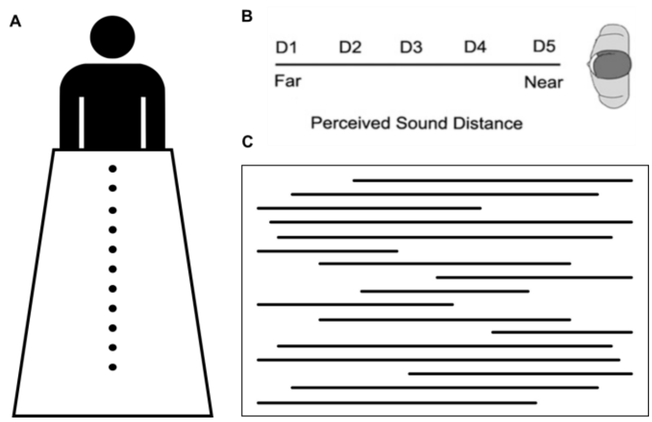

Fig. 2. Schematic representation of the three tasks used to test PPS representation. ***A****: reachability judgment task. The stimuli (black dots) successively and randomly appear at different distances from the participants.* ***B****: multisensory task. Participants respond to tactile stimuli while irrelevant sound move toward or away from them. D1-D5 represent the different distances of the sound (Adapted from Teneggi et al., 2013).* ***C****: line bisection task. Participants mark the mid-point of each line.*

I.1.1. Peripersonal space in the (human and primate) brain

The functional segmentation of the visual space rooted in the sensorimotor system is well established in the scientific community and has been the subject of numerous human and animal studies. At the neural level, Brain (1941) was the first to suggest a dissociation between the "grasping distance" and the "walking distance" when studying brain injured patients resulting in a selective impairment of one of the two spaces. The "grasping" space, in which we can physically interact with our environment, was later named PPS by Rizzolatti et al. (1981). They discovered bimodal neurons (somatosensorial and visual) in area 6 (caudal to the arcuate sulcus in the frontal lobe of macaques) that were selectively activated by stimuli presented within the reaching distance of monkeys. Soon after, they revealed that specific lesions in this region induced inattention to either the space near the monkey or far away from it (Rizzolatti, Matelli, & Pavesi, 1983). More precisely, lesion of the supplementary motor area (area 6) led to neglect objects displayed in the PPS whereas lesion of the frontal eye field (area 8), led to neglect objects in the space far from the monkeys (extrapersonal space). Since then, a lot of animal researches focused on the study of the multisensory (visual, tactile and auditory) neurons of the motor areas in the fronto-parietal areas that specifically respond to PPS (Cléry, Guipponi, Wardak, & Ben Hamed, 2015; Graziano & Cooke, 2006; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997).

The spatial inattention following brain lesions induced by Rizzolatti et al. (1983) in the monkey is a condition known in humans as unilateral spatial neglect, which occurs after a stroke over the fronto-parietal regions of the human brain. Patients with this condition present a deficit of awareness in the contralesional space leading to inattention of objects present in this hemispace (Heilman, Watson, & Valenstein, 1985). It has been found that this impairment of spatial awareness can selectively affect the extrapersonal space (Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998) or the PPS (Berti & Frassinetti, 2000). In this direction, applying

TMS over the parietal cortex of healthy subjects, Bjoertomt et al. (2009) artificially reproduced peripersonal and extrapersonal spatial neglect when targeting the right angular gyrus and the supramarginal gyrus respectively. Furthermore, contralesional PPS neglect can be modulated by multisensory stimulation of space (Làdavas, Pellegrino, Farnè, & Zeloni, 1998). More precisely, the neglect is lessened with multisensory stimulation of the contralesional PPS and worsen with a stimulation of the healthy hemispace or of the contralesional extrapersonal space. These findings strengthen the notion of multisensory integration of space representation, which is specific to the PPS (Cléry et al., 2015; Serino, 2019).

The involvement of the fronto-parietal network in PPS representation has also been confirmed in electroencephalography and brain imagery studies in healthy individuals (Bartolo, Coello, et al., 2014; Culham, Gallivan, Cavina-Pratesi, & Quinlan, 2008; Previc, 1998; Proverbio, 2012; Wamain et al., 2016). Indeed, observing an object within the PPS activates the motor related regions in the parietal cortex (Bartolo, Coello, et al., 2014), and this activation is weighted by the proximity of objects (Wamain et al., 2016). Thus, our brain represents fairly well what is in our PPS and what is not. This discrimination is allowed by the multisensory integration and the motor representation of information surrounding us. However, the boundaries of the PPS representation are not fixed. Instead, they depend on multiple factors. In the following section, we will focus on describing these factors.

I.1.2. PPS representation depends on action

The brain is continuously sending and receiving motor and perceptual-related information. As we adapt constantly our actions to our environment in order to optimize the action-environment interactions, this suggests that PPS representation is flexible and adapts dynamically to the changing sensorimotor context (Coello & Delevoye-Turrell, 2007). For instance, tool-use is known to modify the body schema in human and animal because, while using it, we incorporate tool use to our action system and thus to our body schema (Berti & Frassinetti, 2000; Canzoneri et al., 2013; Cardinali et al., 2012; Maravita & Iriki, 2004). Using a tool with a long handle results in an increase in the PPS representation in human (Bourgeois, Farnè, & Coello, 2014) and animal as well as in an increase in the visual receptive field of the somatosensory neurons in animal (Iriki, Tanaka, & Iwamura, 1996, Fig. 3).

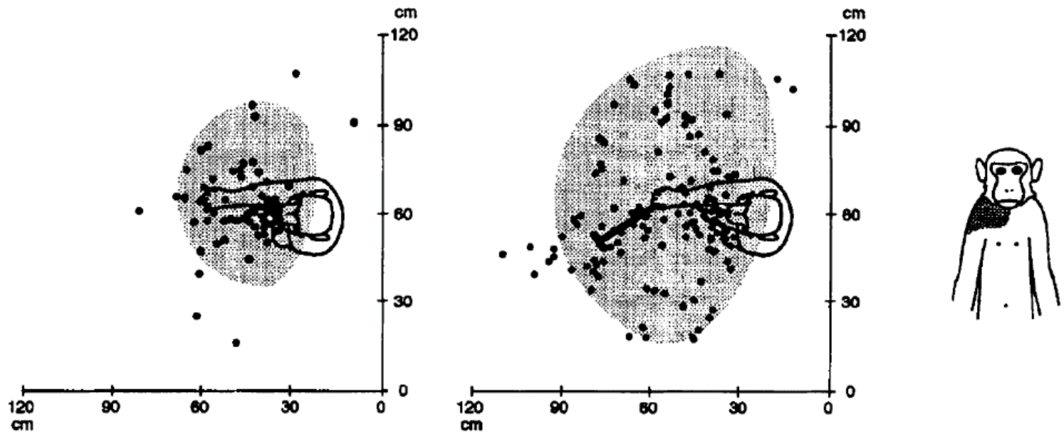

Fig. 3. Visual receptive fields (in grey) of bimodal neurons whose somatosensory receptive fields are located around the shoulder and the neck of a monkey (right panel) before using a tool (left panel) and immediately after using a tool (middle panel). Black dots represent the locations of objects firing neurons. From Iriki et al. (1996)

Interestingly, a decrease in motor action also leads to a remapping of PPS representation. This way, limb immobilization as well as hemiplegia (a unilateral paralysis of half of the body, which includes a paralysis of the arm), induce a reduction of PPS representation during reachability judgment tasks (Bartolo, Carlier, Hassaini, Martin, & Coello, 2014; Toussaint, Wamain, Bidet-Ildei, & Coello, 2018). Also, just like a hit or miss in sport leads to adjustments of the subsequent action, biased biofeedback of an action results in changes in PPS representation (Bourgeois & Coello, 2012). Thus, PPS representation can increase or decrease, depending on the opportunities for action and how the actions are represented. This remapping occurs automatically and unconsciously very quickly as soon as action capacities change.

The extension of PPS representation can also be observed during passive holding of tools by expert users. Thus, actively and passively holding a computer mouse in "expert mouse users" during a multisensory integration task changes PPS representation (Bassolino, Serino, Ubaldi, & Làdavas, 2010). During this experiment, the researchers revealed that task-irrelevant sounds presented near the hand that held a computer-mouse, as well as sounds presented near the screen computer (thus far from participants) enhanced tactile detection in the hand holding the mouse. The same kind of multisensory integration task was used to reveal that while PPS of sighted individuals only increased during a short period of time following the use of a cane, this extension of PPS appeared as soon as blind individuals held the cane (Serino, Bassolino, Farnè, & Làdavas, 2007). Costantini et al. (2014) also revealed that passively holding a tool while observing someone else using the same tool led to PPS adjustment. Taken together, these studies suggest that (1) PPS representation can be durably extended in expert users of a specific tool as soon as the tool is picked up, without requiring any specific manipulation and (2) that this extension is multisensorial.

As a whole, PPS can be seen as a multisensory interface between individuals and their environment whose representation is rooted in the sensorimotor system. PPS is thus influenced by motor expertise and sensorimotor calibration. However, our actions depend on the characteristics of objects we intent to interact with (fragility, dangerousness, etc.). Hence, PPS representation should also be strongly related to objects' characteristics.

I.2. A space depending on the value of objects

Since PPS is an interface between the body and the environment, it makes sense that the value of the objects within the environment also modifies its representation. Indeed, when surrounded by dangerous objects, more attention is given to them and to our actions in order not to be harmed. On the contrary, in the presence of liked objects, we are more incline to interact with these objects than with more neutral ones.

I.2.1. The valence of the stimulus modifies behavioral tendency

Just like children run to an ice cream truck or push their plate of spinach away, our interaction with the environment is motivated by appetizing and aversive values of objects, leading to approach or avoidance behaviors. This hedonic dimension, also called the *valence* dimension is thus a constituent of every element of the environment and extends from positive (attractiveness) to negative (aversiveness) evaluation. Although valence assessment is subjective and depends on our experience with the object to assess (some children like spinach and other dislike ice cream), its *intrinsic* valence can sometimes be conceived as universal because a specific valence is phylogenetically more relevant than another for survival (a snake's bite can be deadly, Elliot, 2008; Öhman, 1986, 2009; Öhman & Dimberg, 1978). Thus, behavioral tendencies (approach or avoidance) apply to each stimulus, depending on their valence (Elliot, 2008).

The concept of approach-avoidance motivation refers to the motivation to initiate behavior toward or away from a positive or negative stimulus respectively (Lewin, 1935). Those two motivations are essential for survival and are largely automatized across species. However, they are also based on ontogenetical processes because of their sensitivity to the environment. Hence, they can vary from one individual to another within the same species, in particular, depending on the contextual environment (Blanchard & Blanchard, 1989). This way, conditioning procedures (i.e., learning procedure in which a neutral stimulus is associated with an attractive or aversive stimulus) can lead to the change in the affective value (valence) of a neutral stimulus (De Houwer, Thomas, & Baeyens, 2001), and to specific approach-avoidance behaviors toward the neutral stimulus (Cooper, Heron, & Heward, 2007; Watson & Rayner, 1920). For example, during the Little Albert experiment, Watson & Rayner (1920) conditioned a rat phobia (leading to avoidance behaviors when facing the stimulus) in a child that didn't show any avoidance behavior to a rat before, by associating the presence of the rat whith that of a loud noise. Furhermore, once established, avoidance behaviors can become quite resistant to extinction (i.e., decrease in the response when presenting the neutral stimulus alone) because they are regarded as safety behaviors with respect to the stimulus in question (Urcelay & Prével, 2019).

With regard to more abstract representations, even concepts, that carry a specific valence but do not represent a direct physical threat or pleasure such as "death" or "love", can be spatially distributed according to the position of the individual. Indeed in an experiment, Marmolejo-Ramos et al. (2018) asked participants to place stickers with valenced abstracts concepts written on it in a 3D space. The authors observed that participants placed positive concepts closer to themselves than negative ones. Accordingly, the representation of the space surrounding the body seems to depend on the action tendency motivated by the valence assigned to the objects that constitute our environment, but also by the willingness to be approached by positive stimuli and to keep our distance from negative ones.

I.2.2. Negative stimuli

The space surrounding the body serves not only object-directed motor behaviors, but is also considered as a safety area in which we avoid the intrusion of threatening or dangerous objects in order to preserve our physical integrity. It is quite simple to imagine that near a chainsaw we decrease the amplitude of our movements to avoid injury. But, as reported above, PPS representation is dependent on our action system and thus, if we reduce the amplitude of our movements, we reduce our action space and our representation of it. Therefore, being near a chainsaw should decrease PPS representation. That is what was observed during reachability judgment tasks with threatening tools or negative objects: PPS representation shrinks (Coello et al., 2012; Valdés-Conroy, Román, Hinojosa, & Shorkey, 2012). For example, Coello et al., (2012) observed a decrease in PPS representation but only when the dangerous part of the object was directed toward participants. Likewise, when participants have to estimate the distance between themselves and a noxious-related object, they underestimate this distance (Tabor et al., 2015). This suggests that the affective value of the elements of the environment changes PPS representation because of the potential harmful consequences of our actions.

Furthermore, Graziano and Cooke (2006) reported that, in monkeys, the multisensory neurons of the ventral intraparietal area and the precentral gyrus respond when an object touches the body or is located near the body. They also respond to object approaching the body and their firing rate increases as a function of the object proximity (Fig. 4). Additionally, potentially noxious stimuli near the body trigger defensive behaviors (Cooke & Graziano, 2003; Graziano, Taylor, & Moore, 2002). In human, the activity of the posterior parietal cortex was found to increase with threatening stimuli within the PPS, suggesting that this region is sensitive to the affective value of a stimulus during its visuo-spatial encoding (Lloyd, Morrison, & Roberts, 2006). Taken together, those results suggest that attention to elements surrounding the body or approaching it seems of paramount importance for survival because it prepares to avoid or to escape the threat. Accordingly, PPS seems to represent a defensive space. If a stimulus, potentially threatening the physical integrity crosses its boundaries, defensive mechanisms are automatically engaged.

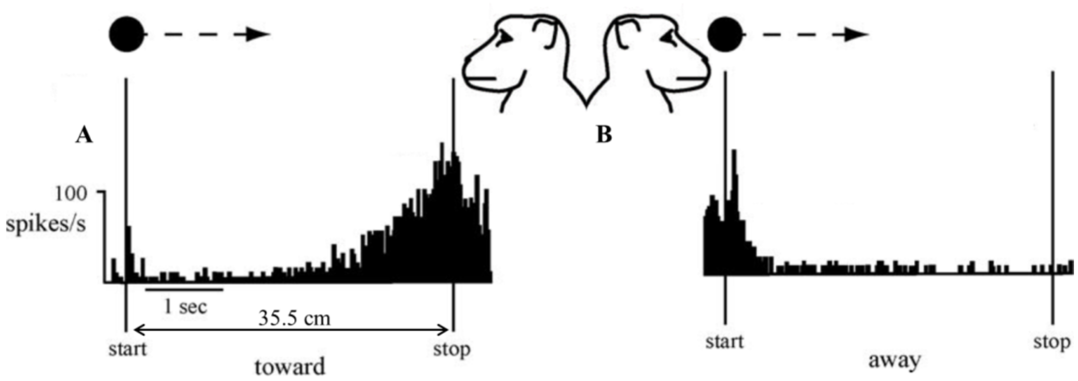

Fig. 4. Activity of a neuron in the precentral gyrus to (A) a ball approaching from the face of a monkey and (B) receding from its face. ***A****: The neuron's response increases with the ball proximity until the ball stops (2 cm away from the monkey's face). When the ball stops, the firing rate decreases but is still elevated.* ***B****: When the ball recedes from the monkey's face, the firing rate rapidly drops. Adapted from Graziano & Cooke, 2006.*

Reaction to threat is thus associated with enhanced vigilance, as if the organism is anticipating the threatening event and prepares to respond to the threat (Lang, Davis, & Öhman, 2000). Threatening phylogenetic as well as ontogenetic stimuli automatically trigger attentional mechanisms and are quickly detected because relevant for survival (Öhman, Esteves, Flykt, & Soares, 1993; Öhman, Flykt, & Esteves, 2001). This has, for example, been highlighted during extinction paradigms with patients suffering from left neglect (Vuilleumier & Schwartz, 2001). During the task, stimuli are simultaneously presented in each of the hemispace of the patients. Compared to healthy participants, patients, already neglecting their left hemispace show even more difficulty in detecting stimuli presented in this portion of space. However, if the stimulus on the left hemispace represents a spider (a phylogenetically threatening stimulus), the extinction effect decreases dramatically (Vuilleumier & Schwartz, 2001). This suggest that threatening stimuli within PPS foster attentional processes. De Haan et al. (2016) showed that approaching picture of spider facilitated visuotactile integration in PPS, and even more for individuals afraid of spiders (de Haan et al., 2016). Taffou and Viaud-Delmon (2014) observed similar effects during an audiotactile task using dog growling with dog-fearful participants. Ferri et al. (2015) obtained comparable results in the general population using negative sounds. Tactile stimulations were detected more quickly if the approaching sounds were negative in comparison to neutral or positive ones. This suggests that proximity to threat fosters the tactile processing. Hence, threat proximity within PPS or close to PPS boundaries seems to enhance defensive mechanisms.

However, some of the results just presented above seem to be contradictory: while Coello et al. (2012) and Valdès-Conroy et al. (2012) reported a decrease in PPS representation with negative stimuli, Hann et al. (2016) and Ferri et al. (2015) observed an increase in PPS representation. These differences could result from the dynamic nature of the stimulus. Indeed, while the first authors used static stimuli (or slided by the experimenter; Valdés-Conroy et al., 2012), the later used dynamic ones, known to increase the defensive representation of PPS (Bufacchi, 2017; Bufacchi & Iannetti, 2018; Graziano & Cooke, 2006). Another explanation might come from the tasks used. Reachability judgments imply action capacities whereas multisensorial integration task relies on stimulus detection, eased with the increased vigilance due to the threatening stimuli and to the anticipation of the looming threat. Thus, these results are not contradictory but demonstrate that strategies to minimize physical risk are sensitive to environmental constraints and can occur in different ways depending on the task. Therefore, it seems more likely that two distinct mechanisms act in the modulation of PPS representation. One relating to motor capacities and intentions and the other relating to defensive strategies and threat anticipation (Fig. 5).

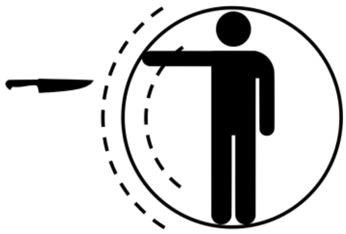

Fig. 5. Schematic illustration of PPS (within the solid circle) representation. The outer dashed curve represents the defensive PPS representation ("I don't' want the knife closer, if it crosses this boundary, my vigilance will be increased") and the inner dashed curve represents the action PPS representation ("This knife is dangerous thus, I reduce the amplitude of my movements, thus what I perceive at hand").

I.2.3. Positive stimuli

Positive stimuli also trigger spatial orientation of attention (Brosch, Sander, Pourtois, & Scherer, 2008; Pool, Brosch, Delplanque, & Sander, 2015). Due to their rewarding and hedonic nature, they elicit approach behaviors, hence, they also should modify PPS representation. To test this, Coello et al. (2018) asked participants to select tokens on a 40-inch touch screen table. The token selected could lead to a reward of 1 point or 0 point, the goal being to obtain the highest final score. Depending on the group (control, near, far), the proportion of rewarding tokens in the near half portion of the table could be of 50%, 75% or 25% respectively (thus respectively 50%, 25% and 75% chance of reward in the far space). Prior and after the token selection task, PPS boundaries of participants were established with a reachability judgment task. First, results revealed that participants of the near group implicitly reduced progressively their token selection to the near space whereas the opposite was observed for the far group. No specific strategy was observed for the control group. Second, PPS boundaries changed accordingly in posttest in comparison to pretest. PPS representation decreased for the near group and increased for the far group. Implicitly modifying the motor exploration of participants by changing the valence of the space led to changes in PPS representation. Similar effects have also been observed in patients with spatial neglect but on the sagittal plane, leading to motor exploration of the left neglected space (Lucas et al., 2013). Thus, PPS representation is dependent on the intention to interact with our environment which is suggested by the valence of the elements that composes it, even when the emotional allocation of that space is not consciously perceived.

Taken together, these data revealed that the perceived valence of the stimuli contributes to the specification of PPS. PPS is sensitive to the valence of the elements of our environment because our actions, and by extension our survival, depend on this valence. Although PPS represents a space for action but also a space for protection, the representation format of the defensive space is not fully understood yet. This suggests however that PPS representation should be influenced by the social context as distance plays a crucial role in social interactions.

I.3. Social dependency of PPS

As a social animal, the representation we have of others' action-space is particularly important and this can be observed at the cerebral level. Just as one's own actions and those of others seems to be coded in a similar way in the monkey brain (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996), similar brain areas respond to the presence of stimuli close to one 's own body and others' body (Ishida, Nakajima, Inase, & Murata, 2010). Indeed, monkeys' visuo-tactile neurons in the parietal cortex fire when visual or tactile stimuli are presented near their body as well as near others' body.

Furthermore, when PPS of two individuals overlap, it results in the modulation of PPS representation. For instance, animal study revealed that if two monkeys share a portion of their PPS in which there is some food, but one of them is a dominant male, the parietal activity of the submissive monkey is dramatically reduced and this later barely tries to get the food (Fujii, Hihara, & Iriki, 2007). This indicates that PPS for the submissive monkey was reshaped. In this situation, the prefrontal activity of the dominant monkey increases whereas that of the submissive one decreases in comparison to when there is no spatial competition for food (Fujii, Hihara, Nagasaka, & Iriki, 2009). Thus, spatial representation relies on the social context and one's PPS is related to the PPS of others.

Similar observations are reported in human studies. Indeed, using a multisensory integration task, Teneggi et al. (2013) revealed that PPS of participants shrank if another individual faced them compared to a mannequin as if they were leaving some space for the other individual. However, authors also reported that, after playing cooperatively with the other person, participant's PPS merged with the one of the other. Likewise, using a multisensory integration task, Pellencin et al. (2017) found an increase in PPS representation when encountering moral individual in comparison to amoral ones. Coello et al. (2018) found similar effects of those observed by Teneggi et al. (2013) during a cooperative task of token selection (as described in section I.2.3). While the amplitude of movement of the two individuals facing each other decreased when selecting tokens, as if they were splitting the work; their PPS representation increased. Interestingly, using the same cooperative task but changing the spatial probability of being rewarded (e.g., 75% chances of getting a reward when selecting a token in the proximal space of one participant, thus 25% in the proximal space of the other), the authors revealed that both the amplitude of movement and the PPS representation increased, but only if the greater chance of success was in the distal space of participants (Gigliotti, Coelho, Coutinho, & Coello, 2019). Taken together, the results suggest that PPS representation is sensitive to social context.

Thus, PPS can be influenced by the social context. When the individuals cooperate in a task, PPS merge to create a shared space of interaction, but only if it is worth it and if it is safe. What is not well known, is how PPS influences our social life when no specific cooperation is required.

I.4. A social space

According to Hediger (1950, 1968), within the same species, organisms naturally maintain a certain distance from each other (Fig. 6). This distance varies depending on the species, correlates with the size of the animal and reflects what Hediger called the personal space. Personal space corresponds to the area surrounding the body of the animal in which no other animal is tolerated. The intrusion in this territory triggers flight or fight behavior until this distance is restored (Blanchard & Blanchard, 1989).

Fig. 6. Flamingos resting respecting a certain distance from each other. From "Wild Animals in Captivity" (Hediger, 1950).

Based on these ethological observations, Hall (1966) focused on the study of this space in human individuals developing a new field of research: the *proxemics*. Proxemics is interesting in how humans use space in a social context. Indeed, as social animals, we operate in a space whose elements also are social entities. During social interaction, individuals maintain a certain distance between each other and the adjustment of this distance is based on a subtle balance between the need to interact efficiently with others and a variety of other factors that seem to be driven by approach-avoidance motivations (Argyle & Dean, 1965). Indeed, if this interval is too large, it is not suitable for social communication, if this interval is encroached upon, it generates discomfort leading to withdrawal (Hayduk, 1978; Lloyd, 2009; Sommer, 1959). Interpersonal distance (hereafter IPD) therefore constitutes the foundation of social interaction, be it verbal or physical. Other concepts related to interaction in the social space such as territory, public distance, social distance, personal distance or intimate distance have been discussed in reference to the purpose of the social interaction and of the size of the social context. In the present thesis, we will focus on the concept of IPD viewed as the optimal distance for allowing dyadic interactions. In the following sections, we will describe IPD basis and modulation.

How to test IPD

Before going any further, it is important to describe how IPD is measured in the different studies that will be mentioned (non-exhaustive, Fig. 7):

- The most ecological method consists in the *observation* of the distance individuals naturally maintain between each other in real-life, without giving them instructions. Those measures can be taken in a waiting room, around a table, while waiting in line, etc. (Sommer, 1959). It has the advantage of implicitly measuring real-life situations but it lacks of experimental control.

- IPD can also be collected using *drawing*. Participants determine the minimum IPD between a target and themselves by marking the line between the two characters at the minimum appropriate distance (Iachini et al., 2016). Even if correlation between IPD obtained using this method and other methods are observed, this method lacks of consistency.

- IPD can also be measured using explicit (active/passive) *stop-distance paradigms* during which the participant/conspecific approaches or recedes from the other until participant stops the trial estimating the last distance as being the minimum comfortable/ appropriate distance (Kennedy, Gläscher, Tyszka, & Adolphs, 2009). This technic explicitly measures IPD. It has the advantage of being very simple and very close to ecological situations but responses are easily influenced by experimental expectations.

- The last method, similar to the reachability judgment task, is the *interpersonal comfort distance judgments task* (later developed in the general method section). Virtual conspecific approaches participants and crosses them at different inter-shoulder distances but disappear before reaching their level. Participants estimate whether inter-shoulder crossing distance is comfortable or not (Quesque et al., 2017). This method implicitly evaluates IPD's boundary.

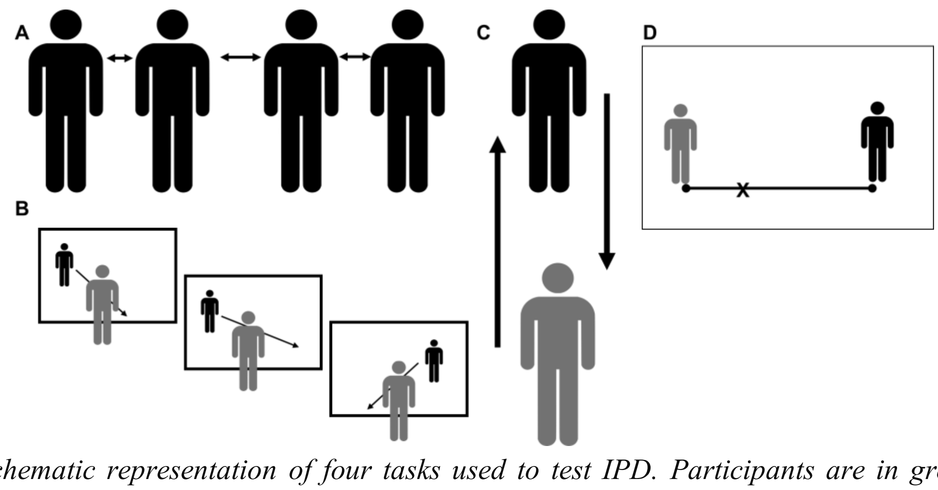

Fig. 7. Schematic representation of four tasks used to test IPD. Participants are in grey and conspecifics in black. ***A****: ecological measurement of IPD.* ***B****: interpersonal comfort distance judgment task. A conspecific approaches the participant at different inter-shoulder distances.* ***C****: stop-distance paradigm.* ***D****: Drawing.*

I.4.1. Relation between IPD and PPS

IPD is at the core of social interaction. Thus, it seems fundamental to understand how it is built. A growing body of evidence suggests that IPD is built on sensorimotor representations. According to Hall (1966), beyond IPD's sensitivity to the degree of intimacy of the individual with the interlocutor, IPD or "personal distance" allows the clear visibility of the others' face and trunk and favors an efficient verbal interaction. At this distance, we can clearly be heard by the other without the need of forcing our voice. Hence, this distance seems particularly suitable for fostering social interactions relatively to sensorial input.

Furthermore, IPD seems to be built on motor representations. IPD is about one arm length and is related to the size of individuals (Hall, 1966; Hartnett, Bailey, & Hartley, 1974; Hayduk, 1983; Pazhoohi et al., 2019). This suggests that this space between individuals is also particularly conducive to potential physical interaction. Moreover, IPD seems to be intrinsically linked to PPS. Indeed, an increasing body of evidence suggests that IPD is built on PPS, although it depends on specific factors (Iachini, Coello, Frassinetti, & Ruggiero, 2014; Iachini, Pagliaro, & Ruggiero, 2015; Quesque et al., 2017; Vieira, Pierzchajlo, & Mitchell, 2019, described in the following section). For instance, Iachini et al. (2014) revealed that IPD decreases in the presence of virtual human-like characters in comparison to non-human-like characters, just as the PPS representation (Teneggi et al., 2013). This suggests that proper social interaction requires a distance between individuals that is sufficiently short (around PPS boundaries) to engage private interaction while ensuring PPS integrity.

Supporting this view, a behavioral study revealed that IPD is sensitive to motor representations (Quesque et al., 2017). In this study, Quesque et al. (2017) asked participants to perform an IPD judgment task with a point-light walker (PLW) that crossed them at different inter-shoulder distances (varying from collision to large inter-shoulder distance) in a virtual environment. The PLW could start from the left or the right side of the participants or right in front of them. Therefore, PLW either crossed participants' midsagittal plane or not (when starting in front of them). Following this session, participants performed a second task during which they had to reach and retrieve tokens displayed at different distances from them with a rake with a short or a long handle. Finally, they performed an ultimate IPD judgment task. First, authors revealed that IPD were larger when the PLW crossed participant's midsagittal plane than when it did not. This could be related to the need for keeping PPS preserved during social interactions. Second, they observed an increase in IPD following the use of the tool with a long handle only. This supports the hypothesis that IPD and PPS share common motor mechanisms and that IPD seems to be built on PPS representation. This hypothesis has also been corroborated by a brain imagery study revealing that the frontoparietal areas known to be involved in PPS representation were also activated by approaching social stimuli (Vieira et al., 2019).

However, other studies (e.g., Patané, Farnè, & Frassinetti, 2017; Patané, Iachini, Farnè, & Frassinetti, 2016) did not observe tool-use effects on IPD adjustment as reported by Quesque et al. (2017). A possible explanation of these divergent results could be related to the influence of the human dimension of the conspecifics combined with a different level of intensity of social interaction. For instance, in their experiments, Patané et al. (2016; 2017) used human conspecifics whereas Quesque et al., (2017) used PLW, focusing on the dynamics of human stimuli rather than body aspects. Furthermore, Patané et al. (2016, 2017) used a (passive/ active) stop-distance-paradigm with conspecifics that approached participants frontally, privileging an explicit measure, whereas Quesque et al. (2017) tool-use effect was observed when PLD crossed participants' midsagittal plane, privileging implicit measure. Moreover, being crossed might not be as socially engaging as being approached from the front (favoring social interaction). The experimental design used by Quesque et al. (2017) might give to low level sensorimotor control more strength, especially if the sense of social presence is only suggested by the perception of human motion (with the PLW). Therefore, for low level sensorimotor processes to take over social factors in IPD adjustment, it seems that the social context should not appeal to explicit social interaction (as probably fostering stereotypical representation). Another point worth mentioning is that in real-life situations, visual elements of the environment can easily be used as a spatial reference. If these landmarks are integrated even implicitly in a the first IPD judgment phase (e.g., the conspecific is at 1 m from the wall), they can be reused in a the second IPD judgment phase. Thus, visual clues (body aspects, spatial references, etc.) combined with a relatively explicit task (Patané et al., 2016, 2017) might limit the effect of body schema recalibration on IPD adjustment. Therefore, although IPD seems to be built on motor representations, its adjustment is also dependent on multiple factors that can be contextual, personal and even be dependent on others' characteristics.

I.4.2. IPD depends on individuals' characteristics

I.4.2.1. IPD depends of idiosyncratic features

As we have seen, IPD adjustment seems to be sensitive to motor representations, but it is also sensitive to the observer's own characteristics. For instance, IPD depends on the observers' age and gender; females keep larger IPD than males do and elders keep larger IPD than youngers do (Iachini et al., 2014, 2016; Ruggiero et al., 2017; Sorokowska et al., 2017). Furthermore, several studies revealed a correlation between the level of social anxiety and IPD (Brady & Walker, 1978; Dosey & Meisels, 1969; Givon-Benjio & Okon-Singer, 2020; Iachini, Ruggiero, Ruotolo, Schiano di Cola, & Senese, 2015). This can be explained by the need to avoid near social interaction (feared stimulus) because individuals suffering from social anxiety are more prone to be afraid of experiencing negative states from these interactions (Nandrino, Ducro, Iachini, & Coello, 2017). Thus, increased distance might help them to tolerate interactions because distancing leads less to interaction and, conversely, the interaction could be conceived as more distant. This interpretation is even more likely when we know that too short IPD leads to discomfort even in people without social anxiety (Kennedy et al., 2009).

Increased IPD is also found in other pathologies associated with high social anxiety such as anorexia (Nandrino et al., 2017), borderline personality disorder (Schienle, Wabnegger, Schöngassner, & Leutgeb, 2015), autistic spectrum disorders (Candini et al., 2017; Perry, Levy-Gigi, Richter-Levin, & Shamay-Tsoory, 2015) or schizophrenia (Horowitz, Duff, & Stratton, 1964; Schoretsanitis, Kutynia, Stegmayer, Strik, & Walther, 2016). On the contrary, disorders associated with a lack of empathy or with antisocial behaviors such as psychopathy lead to shorter IPD (Rimé, Bouvy, Leborgne, & Rouillon, 1978; Vieira & Marsh, 2014; Welsch, Hecht, & von Castell, 2018). Thus, IPD adjustment depends on one's own physical and psychological characteristics. This being said, the characteristics of the individual is not the only source of IPD adjustment, and the characteristics of others must also be considered.

I.4.2.2. IPD depends on others' characteristics

IPD adjustment is sensitive to others' characteristics. Indeed, physical characteristics such as the size of individuals, their age, or their gender modify preferred IPD (Hartnett et al., 1974; Hayduk, 1983; Iachini et al., 2016; Pazhoohi et al., 2019; Uzzell & Horne, 2006). This way, IPD is shorter when the congener is a female in comparison to a male; if he/she is young in comparison to old or if he/she is small in comparison to tall. Regarding the size factor, some authors attributed these results to the level of dominance the size can suggest as if we were making more space to individuals "stronger than us" (Pazhoohi et al., 2019).

IPD adjustment is also dependent on more social factors such as affiliation, because we are more likely to approach individuals with whom we identify with (Fini et al., 2020; Leibman, 1970; Tajfel, Billig, Bundy, & Flament, 1971; F. N. Willis, 1966; Workman, 1987). This way, IPD decreases with in-group members whereas it increases with out-group members (Fini et al., 2020; Hall, 1969; Hendricks & Bootzin, 1976; Leibman, 1970; Tajfel et al., 1971). IPD is also sensitive to morality judgments (Fini et al., 2020; Iachini, Pagliaro, et al., 2015; Pellencin et al., 2017), known to favor approach-avoidance tendencies, as it is the case with other attributes of warmth dimension of social cognition (Fiske, Cuddy, & Glick, 2007).

Finally, IPD adjustment is also sensitive to others' emotional state that can be reflected by their facial expression. This way, individuals with a positive facial expression foster approach behaviors whereas those with a negative facial expression lead to avoidance and withdrawal (Lockard et al., 1977; Ruggiero et al., 2017; Vieira et al., 2017); this results in a decrease and an increase in IPD respectively, which will be more detailed in the next sections. Thus, at equal distance, threatening individuals seem closer to us than non-threatening individuals (Cole, Balcetis, & Dunning, 2013), just like with threatening objects (Tabor et al., 2015).

Thus, just like with action space, IPD adjustment relies on personal as well as others' characteristics such as their affective valence. Since interaction frequently implies motor action, space between individuals during a social interaction seems to be related to the representation of the PPS. However, since it is the interface between ourselves and others, this distance also serves as a margin of protection which prevents from potential harm from others.

I.4.3. What PPS and IPD are to each other?

Are individuals just considered as animated objects when interacting together or is our representation of them specific? While PPS representation has been established as a multisensory space with a specific neural coding, no such thing has been clearly shown for the space of social interactions (Brozzoli, Ehrsson, & Farnè, 2014). We have seen in section I.3 that PPS representation is modulated by others' presence, but so far, social space during interaction that do not require any motor implication from either individual has only been assessed in terms of – comfort – distance (IPD). From studies on the perception of PPS and threat perception in PPS in animals (Graziano & Cooke, 2006) and humans (Bufacchi, Liang, Griffin, & Iannetti, 2016), it was inferred that preferred IPD represents the proximal limit of the "interpersonal space", delimiting the no-go zone during social interactions (Lloyd, 2009). If so, the central object (others) of the interaction is not at the center of this interpersonal space but just *outside* it, unlike objects *in* the PPS. As a consequence, at least at the functional level, interpersonal space does not seem to be comparable to PPS. Therefore, in the present thesis, we prefer to keep using the term IPD which is less subject to misinterpretation than interpersonal space, especially as PPS representation can differ from IPD.

As presented in section I.4.1, a growing body of evidence suggests that IPD is built on PPS representation. First, individuals within reach, just like other stimuli, trigger the activation of fronto-parietal regions involved in PPS representation. However, some regions and connections are more sensitive to the presence of individuals within PPS, such as premotor regions connections to the midbrain periaqueductal grey (Vieira et al., 2019). Furthermore, behavioral studies, conducted by Fini et al. (2020) and Pellencin et al. (2017) shed possible light on the divergent effect of social information observed on PPS representation and on IPD. During their experiment, Pellencin et al. (2017) revealed that the same social factor (amorality) modulated PPS representation (decrease) and IPD adjustment (increase) in opposite directions.

In their study, Fini et al (2020) aimed at investigating whether spatial representation in a social context relied on the *threat hypothesis* or on the *shared experience hypothesis*. To do so, participants had to estimate whether the distance between themselves and virtual characters was near or far until the boundary between the two conditions (near/far) was established. During the first session, characters could be in or out-group members (in comparison to the group of the participants) and during the second session the characters could in addition be moral or criminal.

- According to the *threat hypothesis*, we would perceive negative individuals closer than they really are (leading to an increase in IPD). It is a relatively adaptative behavior because it keeps us more alert to them and also keeps us further away from them so our margin of security is increased if we had to flee from them.
- According to the *shared-experience hypothesis,* it is easier to share the sensorimotor experience of individuals we are "close to". This leads to a decrease in perceived distance with individuals to whom we feel close and to an increase in perceived distance with individuals to whom we do not.

Fini et al. (2020) observed that at a same distance, out-group characters as well as criminal characters were perceived closer than other characters which is in favor of the threat hypothesis. However, regarding PPS representation, Pellencin et al. (2017) found an increase in PPS representation when encountering moral individuals in comparison to amoral ones (using a multisensory integration task) which supports the shared-experience hypothesis. Although further evidence is needed to disentangle these hypotheses, the present studies suggest that in a social context, IPD adjustment relies more on defensive mechanisms related to survival whereas PPS representation remains more strongly related to sensorimotor representations of others. Thus, although IPD appears to be built on PPS, its adjustment is influenced by social factors in a different way than PPS is.

Altogether, IPD seems to be built on the PPS which can be seen as a multisensory interface rooted in the sensorimotor system whose representation is also strongly relying on defensive mechanisms. IPD is specifically sensitive to factors related to ones' own and others' characteristics such as their facial expression of emotion. In the next section, we will present more precisely to what extent facial expressions are a precious tool to study IPD adjustment since they are a marker of others' emotional state and, thus, of potential threat. We will present how emotional facial expressions preferentially capture attention, automatically trigger behavioral responses and can alter our representation of others facial expressions.

II. THE PROCESSING OF EMOTIONAL INFORMATION

As introduced in the previous section, IPD adjustment depends on PPS and on the information conveyed by others. In particular, IPD depends on the physical information with an emotional content because it reflects the emotional state of others as well as their behavioral intentions (Darwin, 1872; Waller, Whitehouse, & Micheletta, 2017). The emotional information from others is an emotional response to an emotional event itself. Even if emotions do not have a consensual definition; it is well admitted that emotions are rooted in their expression which includes intense bodily reactions as they prepare for adaptive action tendencies (Scherer, 2005). The duration of their expression is short as a result of the massive mobilization of the body. According to Scherer (2005), an emotional episode can be divided into five components: cognitive, neurophysiological, motivational, behavioral and one related to the subjective feeling of the emotional episode. For instance, when we see someone on the street who seems upset, making gestures and having a scowling face, we increase our distance from that person. In that example, we inferred an emotional state to the other person on the basis of his/her physical behavior and adjusted our own behavior accordingly. Here, the increase in IPD was related to the emotional response to the individual that we perceived as a threatening stimulus.

In this thesis, we decided to focus on emotional facial expression (FE) as a vector of emotional information as, we will see, it triggers strong emotional responses and it is easily and automatically identified. In this section, we will thus present how emotional FE automatically and preferentially draws attention and produces motor reactions supposed to favor their recognition. We will also present how one specific emotional FE can modify the way we perceive a FE subsequently presented.

II.1. Facial expression: a relevant emotional information from others

Conveying emotional states through the body is not specific to human beings, it is found in many animal species. Therefore, these manifestations share some characteristics from one species to another (Darwin, 1872; Hediger, 1968). Hence, fearful reactions, as illustrated in Fig. 8, lead to hair erection, contraction of the platysma muscle (muscle in front of the neck), and pupil dilatation to numerous species (Darwin, 1872).

Fig. 8. Fearful reaction from a cat afraid by a dog. Illustration from M. Wood in "Expression of emotions in man and animals" (Darwin, 1872).

The body expresses emotional state in an automatic way, protecting the body from external hazard (Graziano & Cooke, 2006) and, at the same time, allows others to understand this state and adjust their behavior accordingly (Crivelli & Fridlund, 2018; de Gelder, 2006). These biologically relevant nonverbal behaviors include body gestures (Atkinson, Dittrich, Gemmell, & Young, 2004), body posture (Tamietto et al., 2009), emotional FE (Ekman & Friesen, 1971), speech prosody such as pitch (Frick, 1985) and pupil-size (Kret & De Dreu, 2019). In humans, FE are probably the most studied nonverbal behavior. Except for neutral FE, which can be seen as "ambiguous" and "emotionless" stimuli (Ekman & O'Sullivan, 1988), emotional FE are particularly relevant during social interaction because they inform us about the emotional state and the behavioral intention of others (Darwin, 1872; Ekman & Friesen, 1971; Ekman & O'Sullivan, 1988; Waller et al., 2017). They are biologically relevant social stimuli (Keltner & Haidt, 1999; Öhman & Dimberg, 1978), identified early in children development (Stifter & Fox, 1987). They are also the most influent social clues among non-verbal behaviors, and the ones individuals are looking the most during social interaction (Gullberg & Holmqvist, 2006). Although FE have a universal basis because of their genetic foundation, cultural and environmental features also shape them differently

(Ekman, 1980). Therefore, FE are influenced by the individual experience and their recognition and evaluation are also dependent on the observer's experience and the context in which they are perceived (Ekman, 1980; Russell & Fehr, 1987; Wedell & Parducci, 1988).

II.1.1. Facial expression, a biologically relevant stimulus

FE are processed very quickly and automatically by observers (Esteves & Öhman, 1993). Emotional FE are important clues during social interaction because they guide our behaviors with others. For example, they automatically capture attentional resources (Palermo & Rhodes, 2007; Vuilleumier, 2002). This is supported by studies on patients with left spatial neglect. As described earlier, they suffer from extinction of the contralesional space. This extinction is even more pronounced when a face is presented in the ipsilesional space and, on the contrary, patients neglect less their contralesional space when a face appears in it (Vuilleumier, 2000). Furthermore, attentional processing (Putman, Hermans, & van Honk, 2004) and automatic reactions to FE perception (de Gelder, Vroomen, Pourtois, & Weiskrantz, 1999; Tamietto et al., 2009) can be triggered without conscious perception of FE. Indeed, patients with a blindsight (residual visual capacities following the partial destruction of the visual cortices, preventing them from any form conscious visual perception in a part of their visual hemifield) have emotional responses (pupil dilatation and facial mimicry) congruent with the emotion presented when displayed in the blind hemifield (de Gelder et al., 1999; Tamietto et al., 2009).

Negative FE (with a threat-relative value) are thought to be particularly important for survival. Their effect on attentional processing have been particularly studied (Öhman, 1987; Öhman & Mineka, 2001). For example, in healthy individuals, negative FE preferentially capture attention and their simple presence can disrupt performances in a main task (e.g., increased reaction time, error rate, etc.; Eastwood, Smilek, & Merikle, 2003; Hansen & Hansen, 1988; Phelps, Ling, & Carrasco, 2006; Putman et al., 2004). As negative FE are relevant for survival, the dysfunctional processing of these emotional cues might contribute to develop and maintain psychopathological disorders. For instance, these effects have been observed in individuals with deficits in social interaction such as patients with social anxiety (B. Bradley, Mogg, White, Groom, & de Bono, 1999). Indeed, high level of social anxiety is often associated with attentional bias toward threatening FE and associated with deficits in goal-directed control of attention when the emotional context of the task consists of threatening FE (B. Bradley et al., 1999; Delchau et al., 2020; Eysenck, Derakshan, Santos, & Calvo, 2007; Gilboa-Schechtman, Foa, & Amir, 1999). Hence, individuals with high levels of social anxiety, which can be associated with fear of negative evaluation from others, are more accurate in negative FE recognition task than individuals with lower level of anxiety (Winton, Clark, & Edelmann, 1995). In addition, their subjective evaluation of negative FE is often more intense and often experience more negatively than for individuals without anxiety (Dijk, Fischer, Morina, van Eeuwijk, & van Kleef, 2018; Dimberg & Christmanson, 1991).

Thus, because they are informative about others' emotional state and potentially negative behavioral intentions, negative FE preferentially trigger attention. This seems particularly adaptative as it allows to adapt our behavior accordingly; including an increase in IPD. However, in social anxiety population, individuals suffer from deficits in disengaging attention from negative emotional signals which might lead to inappropriate avoidance behavior, including an oversized IPD.

Although historically threat-relevant stimuli detection seemed to bias face detection, positive FE also preferentially capture visual attention. This can be in line with their rewarding value and their tendency to favor approach behaviors (Elliot, 2008; Pool et al., 2015). Indeed, positive FE foster approach behaviors because mostly associated to pleasure (Öhman & Mineka, 2001). Thus, positive and negative FE have been found to similarly capture visual attention (Brosch et al., 2008). Furthermore, some studies did reveal that happy FE seem to be detected faster and more accurately than neutral, fearful and even angry ones (Esteves & Öhman, 1993; Juth, Lundqvist, Karlsson, & Öhman, 2005). Finally, the "face in the crowd" paradigm, that first highlighted bias toward negative FE, also revealed a bias toward positive FE in healthy individuals (Becker, Anderson, Mortensen, Neufeld, & Neel, 2011; Juth et al., 2005; Vermeulen, Pleyers, Mermillod, Corneille, & Schaefer, 2019). This paradigm consists in detecting whether a target is present or absent among distractors. Note that, the ability to rapidly detect happy FE is impaired in patients suffering from depression (Suslow, Junghanns, & Arolt, 2001). This supports previous results suggesting that our own emotional state can disrupt the attentional processing involved in FE detection.

Thus, the perception of emotional FE, whether positive or negative, automatically capture our attention, although this orientation is sensitive to psychological factors. The attentional orientation toward emotional FE is critical as it allows to trigger approach-avoidance behaviors. Furthermore, as we will present in the next section, this attentional orientation is accompanied by specific automatic motor behaviors supposed to favor the fast recognition and understanding of others' emotional state: rapid facial reactions (i.e., facial mimicry).

II.1.2. Behavioral response from the body

In order to facilitate the understanding of others' emotional state, we automatically mimic their FE (McIntosh, Reichmann-Decker, Winkielman, & Wilbarger, 2006). According to the embodied theories of cognition, facial mimicries (rapid facial reactions) can be seen as the motor simulation of the perceived FE, facilitating their recognition and the understanding of others' emotional state. Facial mimicry can occur during unconscious perception of FE (Dimberg, Thunberg, & Elmehed, 2000; Tamietto et al., 2009) but they are potentiated by direct eye contact (Soussignan et al., 2013). Furthermore, facial mimicry's intensity is sensitive to emotional induction presented before the FE exposition (Moody, Mcintosh, Mann, & Weisser, 2007). On the contrary, blocking facial muscles has an impact on FE's recognition and on the evaluation of their intensity (Heckmann, Teichmann, Schröder, & Sprengelmeyer, 2003; Oberman, Winkielman, & Ramachandran, 2007).

In addition, facial mimicry is automatically produced when observing emotional state conveyed by the whole body (Grèzes et al., 2013; Tamietto et al., 2009). The intensity of the facial reaction is stronger if the body is oriented toward the observer and is related to the emotional intensity of the body posture (Grèzes et al., 2013). Facial activation can also be observed during unconscious perception of emotional body expression (Tamietto et al., 2009). Indeed, authors observed congruent facial activation when displaying FE in the blind hemifield of patients with a blindsight, but also when displaying bodily emotional expressions. Furthermore, facial reactions to FE can also be interpreted as automatic markers of action preparation in relation to the emotional state of others. As mentioned before, others' FE provide information regarding their emotional state and their behavioral intention (Waller et al., 2017). Thus, they can be considered as cues on how to behave with them accordingly. Hence, perception of emotional FE produces electrophysiological changes (developed in section III), leading to action tendency. Moody et al. (2018) revealed that these automatic and unconscious motor reactions to FE can spread to other parts of the body. Indeed, they observed both facial mimicries and contraction of the muscles of the arm of participants while observing FE. The muscular contractions of the arm were congruent with fist-making and hand-raising when participants observed angry and fearful faces respectively. Thus, the motor simulation seems to recruit the whole body when perceiving emotional FE and therefore initiate approach-avoidance behavior.

Interestingly, some psychopathological disorders associated with a deficit in emotional FE recognition or in the evaluation of their intensity show atypical facial mimicry. For instance, individuals with high psychopathic traits have difficulties identifying FE of fear (Montagne et al., 2005) and are more likely to interpret ambiguous FE as angry expressions (Schönenberg & Jusyte, 2014). In addition, they tend to produce more angry FE than healthy ones (Fanti, Kyranides, & Panayiotou, 2015; Lavallée, 2020) as well as reduced facial mimicry when perceiving negative FE, again in comparison to healthy controls (Fanti, Panayiotou, Lombardo, & Kyranides, 2016; Herpertz et al., 2001). Furthermore, some authors revealed that individuals suffering from depression have difficulties identifying FE of happiness. They hypothesized that it could be linked to their general tendency to express sadness (Joormann & Gotlib, 2006). However, although depressed patients also show reduced facial mimicry to happy FE, this impairment is only weakly correlated to their impairment in happy FE recognition (Zwick & Wolkenstein, 2017). Moreover, patients suffering from borderline disorder, a pathology associated with deficits in social interaction, can show impairments in emotional FE recognition (Niedtfeld et al., 2017). They also produce more intense facial mimicry when perceiving negative FE and attenuated ones when perceiving positive FE (Matzke, Herpertz, Berger, Fleischer, & Domes, 2014). Surprisingly, individuals with social anxiety show decreased facial mimicry in response to negative and positive FE (Dimberg & Christmanson, 1991). Other researchers did not find any difference between healthy and anxious individuals on emotional facial mimicry, but their methodology was based on estimates of action units' intensities (using a software analyzing face movements with a camera). This measurement might be less sensitive than electromyography (recording of the electrical activity produced by the muscles, Dijk et al., 2018). Both results are nevertheless quite surprising because as anxious individuals experience negative social interaction more negatively than healthy individuals, one might expect them to show enlarged negative facial mimicries. According to the authors, the affiliative value of mimicry and the tendency for anxious population to adopt submissive behaviors can partially explain why this population expresses weaker facial mimicry to negative FE. Anxious individuals usually prefer to avoid social interactions, therefore, they might also restrain their nonverbal behaviors in order to avoid fostering any social interaction (Dimberg & Christmanson, 1991). Taken together, those results suggest that the ability to identify others' FE can rely, at least in part, on motor representation of the emotion.

To summarize, facial mimicry seems to be automatically initiated in order to facilitate the understanding of others' emotional state and seems to be accompanied by motor preparation of the body congruent with the situation. When impaired, it can contribute to develop and maintain specific psychopathological disorders or on the contrary, to be the result of it. Furthermore, it is interesting to keep in mind that some of these pathologies associated with a deficit in facial mimicry (i.e., social anxiety, borderline disorder and high psychopathic traits) are also associated with deficits in IPD adjustment (Brady & Walker, 1978; Dosey & Meisels, 1969; Iachini, Ruggiero, et al., 2015; Nandrino et al., 2011; Schienle et al., 2015; Vieira & Marsh, 2014; Welsch et al., 2018). Taken together, those results suggest that the ability to identify others' FE relies in particular on motor representation of the emotion. Those processes are modulated by the emotional state of the observer. Therefore, our own (facial) motor representation seems to contribute to the perception of others' FE and to our ability to infer their emotional state. This can lead to behavioral adjustments such as increase or decrease in IPD.

In the next section, we will present how the context, as a referential, affects our representation of a target. In particular, we will present how the emotional context, represented by emotional FE of others, can influence the way we perceive neutral FE, as they are more ambiguous with regards to the emotional state of others.

II.2. Context-dependency on judgment

The representation of other individuals, and more generally, of the elements that surround us is not only dependent on their intrinsic properties but also on the relation of all of the other elements surrounding them (Kahneman & Tversky, 1979; Louie, Grattan, & Glimcher, 2011; Parducci, 1965). This contribution of contextual elements in stimulus judgment has led researches to investigate the *relative* and not absolute nature of our judgments (Kahneman & Tversky, 1979). For example: if we have to estimate (which is by definition subjective) a temperature in degrees (say 20°C, an absolute value), our estimate will not be the same if we were previously exposed to a temperature of 0°C or 40°C (context). Thus, our estimation is context-dependent, or relative to the context. Therefore, in parallel to low-level reactions to the perception of emotional stimuli (presented in section II.1), more elaborated processes are also automatically set up. The stimulus and the whole situation in which the stimulus is embedded in (currently and previously) is assessed. The assessment of the context impacts the assessment of the emotional experience associated with the stimulus (Noel et al., 2020; Parkinson, 2001, 2019).

The relative nature of judgements was first studied in regard to the "reference-point" or referential (Helson, 1964; Kahneman & Tversky, 1979). According to this theory called Prospect Theory, individuals do not evaluate the absolute value of a target, but rather its "distance" from a reference-point. Changing of referential can thus dramatically change our representation of the same stimulus. Since the referential is itself derived from the context, changing the context modifies the referential which in turn changes the judgment of the stimulus (framing effect, Kahneman & Tversky, 1979).. Moreover, as illustrated in Fig. 9, the context is not only relative to the elements encountered at the same time as the target to be judged: *spatial context*, but also to the other elements encountered so far: *temporal context* (Louie et al., 2011).

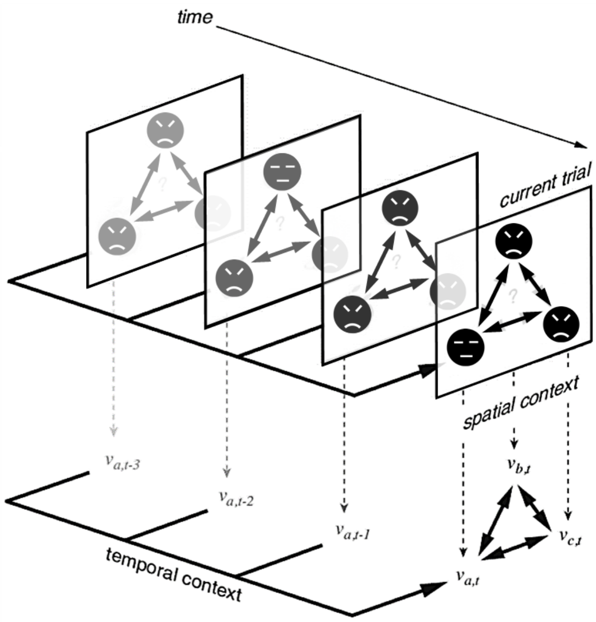

Fig. 9. Schematic representation of the spatial and the temporal context on decision-making. The spatial influence of the context on choice decision is illustrated by the values (V_{at}, V_{bt}, V_{ct}) of the different stimuli at the time of the evaluation (t). The temporal influence of the context is illustrated by the previous trials (t-1, t-2, t-3). Adapted from Louie et al. (2015)

This context-dependency can be found in several animal species and applies to several fields that require decision making (Louie et al., 2015). Different theories have been proposed (some of them will be presented below), taking into consideration different formalizations of the relationship between the target and its context. In this outlook, two opposite effects can be observed when studying context effect on judgment: an assimilation effect and a contrast effect. The *assimilation* effect can be defined as a tendency to shift the judgment of a target stimulus toward information that has already been activated (the context). The *contrast* effect can be seen as the tendency to compare the target to information that has already been activated thus, resulting in a shift toward the opposite direction to that of the context (Diederik A. Stapel & Winkielman, 1998). The reason why one of these effects is observed rather than the other seems to depend on different factors including task demands (and effect of the instruction), similarity between the target and the context elements, and ambiguity of the information to be judged (Diederik A. Stapel & Winkielman, 1998; Unkelbach & Fiedler, 2016; Wedell, Parducci, & Geiselman, 1987). However, specific procedures such as evaluative conditioning (presented below) or reproduction from memory seems to favors the emergence of assimilation effect whereas explicit judgments seems to favor contrast effects (De Houwer et al., 2001; Huttenlocher, Hedges, & Vevea, 2000; Wedell et al., 1987).

Mathematical formalizations have been proposed to predict how the subjective evaluation of a stimulus depends on the values of the context. However, depending on the model under investigation, the formalization of the context differs. Usually, the evaluation of the stimulus relies on the mean, the range or the rank with respect to the other contextual stimuli. In the next sections, we will present different procedures leading to assimilation effect as well as the category adjustment model formalizing this effect. We will also detail contrast effect and describe major theories characterizing it: the divisive normalization model, the range-frequency model and the geometric model of emotion.

II.2.1.Assimilation effects

Assimilation effect of emotional information is quite intuitive, loosely speaking: if I see someone that I don't know with someone I dislike; I will probably dislike this person too. This effect has been observed when assessing the physical attractiveness of a target face presented together with other faces more or less attractive than the target (Geiselman, Haight, & Kimata, 1984). Those effects were even stronger when the individuals on the picture were described as being friends (Geiselman et al., 1984; Wedell et al., 1987). Yet, Stapel & Winkielman (1998) observed that assimilation effect was also fostered when suggesting dissimilarities between the target (a human) and the context (an ape). Thus, literature focusing on the observation of assimilation effect of the context does not agree concerning the factors fostering it (similarity vs dissimilarity). However, specific experimental procedures can favor the appearance of assimilation effect.

II.2.1.1. Procedures favoring assimilation effect

Evaluative Conditioning (EC) is a procedure that consists in changing the evaluation (liking) of a neutral stimulus (conditioned stimulus, CS) after a pairing between this stimulus and an affective one (unconditioned stimulus, US). The change goes in the direction of the valence of the affective stimulus (De Houwer et al., 2001; Unkelbach & Fiedler, 2016). Like an assimilation effect, if a neutral stimulus is paired with a negative stimulus, it will be less liked than before the pairing. On the contrary it will be more liked after having been paired with a positive stimulus.

EC refers to some extent to a Pavlovian conditioning procedure. It consists in repeatedly presenting an emotional stimulus shortly after the occurrence of the neutral stimulus (temporal contiguity). Following this procedure, the presentation of neutral stimulus alone should trigger a conditioned response (or its expression) similar to the response observed following the presentation of an emotional stimulus alone. Although CS-US association is usually learned following forward conditioning procedure (presented above), it can also be learned using backward procedure (emotional stimulus followed by neutral stimulus presentation) or during simultaneous presentation of the stimuli (De Houwer, Hendrickx, & Baeyens, 1997; Hofmann, De Houwer, Perugini, Baeyens, & Crombez, 2010).

The strength of the association (that can be evaluated via the intensity of the conditioned response or its expression), therefore the assimilation effect of the emotional context (Unkelbach & Fiedler, 2016), depends on multiple factors. For instance, the saliency of the emotional stimulus determines, in part, the strength of the association between the neutral and the emotional stimuli (Rescorla & Wagner, 1972). Therefore, during EC, subliminal presentation of the emotional stimulus have low impact on the liking of the neutral stimulus (De Houwer et al., 1997; Hofmann et al., 2010). Furthermore, the strength of the association (that can be evaluated via the intensity of the conditioned response) also seems fostered by the contingency awareness (awareness of the CS-US relation, De Houwer et al., 1997; Hofmann et al., 2010). However, even when individuals are explicitly informed of the potential influence of the emotional stimulus on the neutral stimulus rating, they fail to notice this influence and thus, they fail to control it leading to assimilation effect (Sava, Payne, Măgurean, Iancu, & Rusu, 2020).

Other experimental procedures can favor the emergence of assimilation effect. For example, in priming procedure, stimuli are more liked after the subliminal exposure to a positive face, and less after a negative face (Murphy & Zajonc, 1993). Figure reproduction and recognition are also known to favor assimilation effect (Corbin & Crawford, 2018; Griffiths, Rhodes, Jeffery, Palermo, & Neumann, 2018; Huttenlocher et al., 2000). For instance, in their experiment, Corbin & Crawford (2018) presented a neutral FE (the target) together with a set of sad (or happy) FE. At their disappearance, a new face appeared at the location of the target informing participants to recall the expression that was previously in that location. Among the morphed expressions (ranging from very happy to very sad), participants chose a sadder (or happier) FE than the target was. This assimilation effect refers to Bayesian updating and can be formalized by the category adjustment model.

II.2.1.2. Bayesian Updating: Category Adjustment Model (CAM)

The Category Adjustment Model (CAM) is a mathematical formalization of Bayesian updating (Duffy, Huttenlocher, Hedges, & Crawford, 2010; Huttenlocher et al., 2000). When evaluating a stimulus, both the information from this new stimulus and prior exposition to the other stimuli (context) are taken into account. Once this evaluation is performed, the information from this stimulus is used to update and refine the contextual information (believes).

More precisely, this model is based on the central tendency bias. According to this bias, individuals tend to shift their evaluation of a stimulus toward the perceived average of all the stimuli encountered so far while considering (fine-grain) mental representation of the stimulus values (Duffy et al., 2010; Huttenlocher et al., 2000). The weighting of these two factors (category's central value and fine-grain details) when estimating the stimulus depends on the degree of accuracy (uncertainty, σ^2) of both the category's central value (ρ, stimuli seen before) and the fine-grain memory of the current stimulus (*M,* Fig. 10). For this model the main parameter considered is therefore the mean, together with the standard deviation. Thus, at each new estimate (*R*), the dispersion of the category's central value (σ_ρ^2) and that of the fine-grain memory (σ_M^2) modify their weight (λ) as a Bayesian update according to:

$$R = \lambda M + (1 - \lambda)\rho \qquad (1)$$

where:

$$\lambda = \frac{\sigma_\rho^2}{(\sigma_\rho^2 + \sigma_M^2)} \qquad (2)$$

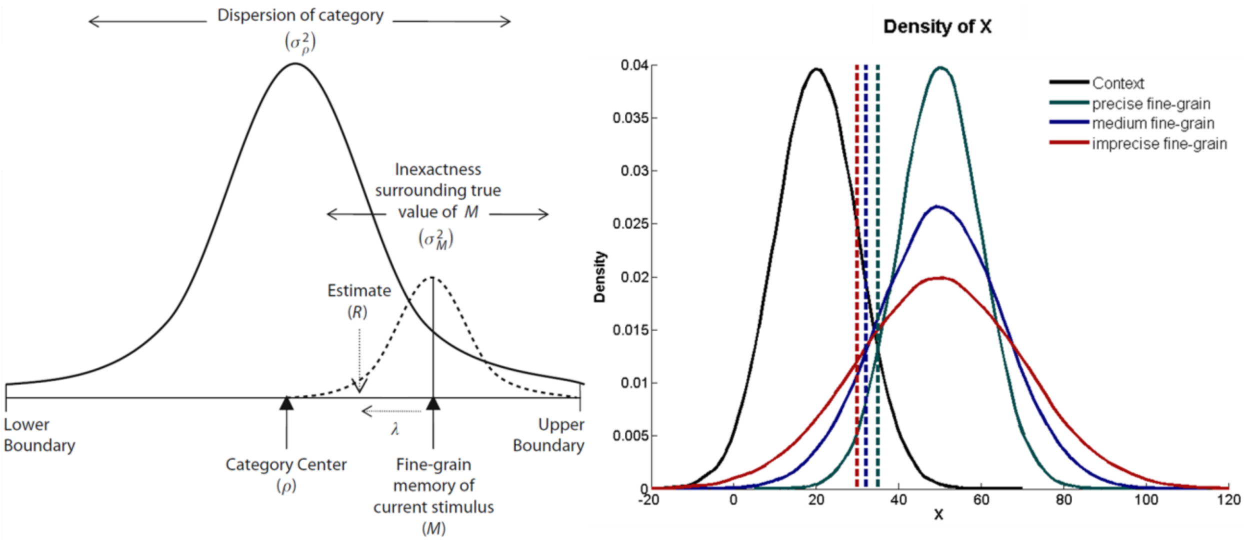

Fig. 10. ***Left panel:*** *Schematic representation of equation (1)*(18*) with a normal distribution of the category's central value (ρ) and of the fine-grain of the stimulus (M). The weight (λ) is depending on the dispersion of both the category's central value (σ_ρ^2) and of the fine-grain (σ_M^2), thus the estimate (R) shifts toward ρ. Adapted from (Duffy et al., 2010).* ***Right panel:*** *Simulation of equation (1)*(18*) for the targets (colored solid lines, mean = 50) depending on their fine-grain (precise – sd = 10 – in green, medium, – sd = 15 – in blue, imprecise – sd =20 – in red), with a normal distribution of the category center (solid black line, mean = 20, sd = 10). Dashed vertical lines represent estimates for each target.*

Hence, for a given dispersion of the category (standard deviation of the context) the less precise the fine-grain details of the target are, the greater its standard deviation, and the more the estimate will be influenced by the mean of the context. Therefore, the estimate will shift toward the mean of the context (the right panel of Fig. 10).

To summarize, assimilation effect of the emotional context can be observed through different procedures and have formalizations that can describe it precisely. However, when assessing neutral (or average) stimuli, opposite effect of the context can also emerge: contrast effect.

II.2.2. Contrast effect

Contrast effect refers to a negative correlation between the judgment of the target and the value of the context (Schwarz & Bless, 2007). It has been studied in many different areas such as judgment of square size, painting beauty or women attractiveness (Cash, Cash, & Butters, 1983; Parducci, 1965; Tousignant & Bodner, 2018; Wedell et al., 1987). For example, when presenting pictures of average attractive women, individuals rate them as less attractive if they are presented in a context of highly attractive women than if they are presented in a context of less attractive ones (Wedell et al., 1987). Contrast effect has also been observed when assessing the valence of a stimulus. Indeed, emotional pictures of actors (Manis, 1967), driving situation (Krupat, 1974), drawings of emotional faces or verbal descriptions of life events (Wedell & Parducci, 1988) can also be subject to contrast effects.

According to Stapel & Winkielman (1998), similarities between the context (an ape) and the target (a human) favor a contrast effect of the context whereas dissimilarities between the two favor an assimilation effect. Furthermore, regarding FE evaluation, contrast effect can be observed with various contextual emotional information (or external features) such as other faces, verbalization of emotional words, verbal or written emotional description of social situation or visual scenes. (Manis, 1967; Unkelbach & Fiedler, 2016; Wedell & Parducci, 1988; Wieser & Brosch, 2012). This suggests that contrast effect is not as sensitive to the similarity between the target and the contextual elements as suggested by Stapel & Winkielman (1998). However, salient context and explicit judgment tasks appear to promote contrast effects (Kobylínska & Karwowska, 2014; Martin, Seta, & Crelia, 1990).

Although different models propose a formalization of contrast effect, we decided to focus on three models: the geometrical model (Russell & Fehr, 1987), the Divisive Normalization model (Louie et al., 2011) and the Range-Frequency model (Parducci, 1965), because they were tested on facial stimuli.

II.2.2.1. Geometric Model of emotional space

The Geometric Model of emotional space has been proposed by Russell and Fehr (1987) and is based on the circumplex model of affects (Russell, 1980) according to which affective experiences can be represented on a two-dimensional circular space whose cardinal points represent pleasure-displeasure and arousal-sleep dimensions (Fig. 11, left panel). The geometric model is a spatial model and is based on the assessment of FE on this two-dimensional representation of affects. According to this model, the assessment of a FE (anchor) shifts the evaluation of a next FE (target) with respect to its "original" assessment (if there had been no other evaluation before). This shift takes into account the polar coordinates (distance and angle) of the anchor according to the origin of the two-dimensional representation circle (0 x units, 0° position), "pushes" the target in the opposite direction with respect to its "original" position (Fig. 11) and in relation to the distance between the anchor and the origin of the circle (contrast effect).

Thus, Russell and Fehr (1987) asked a group of participants to assess a neutral FE (target in Fig. 11, right panel) only, and asked another group to assess a happy FE (anchor, A in Fig.

11) then, to assess the neutral target. The anchor obtained polar coordinates of 10.83 units and 7.28° from the circle origin. According to their predictions, the shift in the assessment of the neutral target should fall in the opposite direction at 180° + 7.28° (thus 187.28°) from its original point. They observed a shift of 184.4° (E_1 in Fig. 11). Furthermore, they observed, through multiple experiments that the distance between the original position of the target and the shifted position (E_1) represented about 40% of the polar distance between the anchor and the origin of the circle. The neutral target was evaluated as sadder by the second group than by the first one who did not assess the happy FE before. Interestingly, this shift was also observed geometrically; E_1 was translated toward the space of "sad" representation of FE (spatially opposed to happy representation, in Fig. 11, left panel).

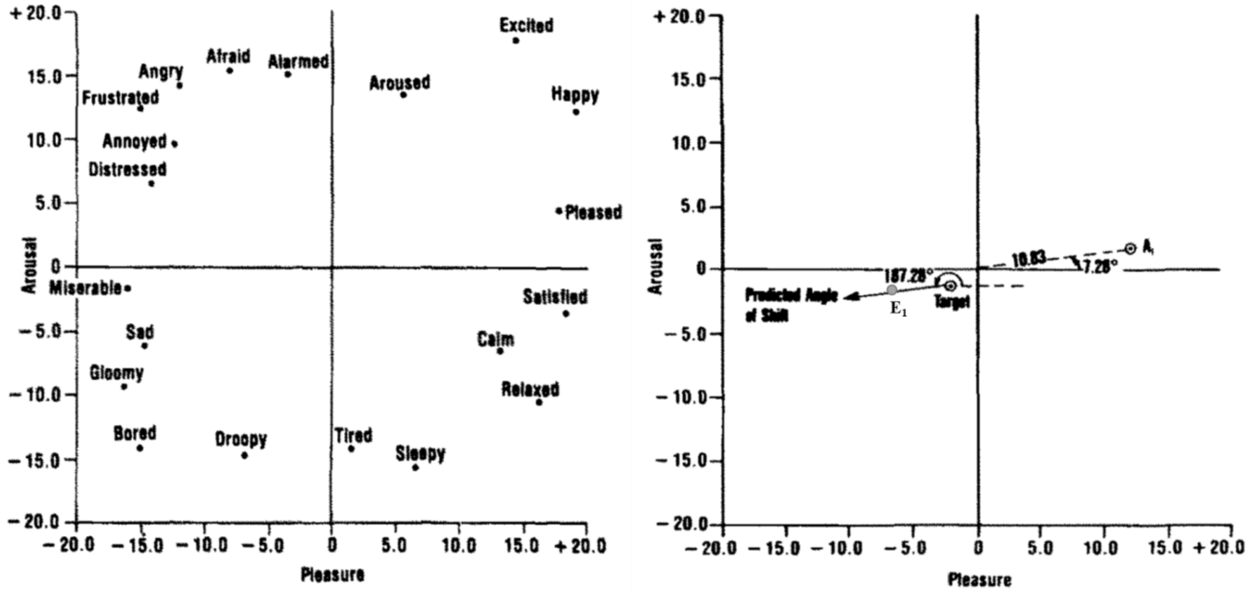

Fig. 11. ***Left Panel:*** *two-dimensional map of 28 emotional words.* ***Right Panel:*** *Example of displacement of a neutral FE (target) induced by the assessment of the Anchor (A). The solid arrow represents the predicted direction of the shift. The target point represents the original position of the neutral FE and E_1 (in grey), the observed shift in the assessment of the target induced by the assessment of A. The E_1 assessments shifts toward the "sad" representation of FE (opposite to happy in the two-dimensional map). Adapted from (Russell & Fehr, 1987)*

This geometrical representation of the contrast effect is interesting for us since it was implemented to directly assess the effect of affective context and in particular emotional FE

(Russell & Fehr, 1987). However, the spatial framework on which this model is based (two-dimensional map of emotional words) is also subjective (Russell, 1980). Moreover, its structure can hardly compete with models based on a strong mathematical formalization as it is based on empirical observation and lack of strong theoretical support.

II.2.2.2. Divisive Normalization Model

The Divisive Normalization (DN) model also predicts contrast effect. This physiological model was initially developed to understand how visual neuron's firing rates are suppressed by stimuli that are on the periphery of their receptive field (Glimcher, 2014). However, this context-dependent neural activation can be found in multiple brain areas implied in sensorimotor integration (Louie et al., 2015). During a perceptual discrimination task (Fig. 12), monkey's individual neurons of the lateral intraparietal cortex (involved in eye movement), discharge more or less depending on the value of the stimulus toward which the saccade will be directed to (within the receptive field or not), but also depending on the value of the alternative stimuli that are outside of the neurons' receptive field (Louie et al., 2011). Hence, the firing rate can represent the "willingness" or "desirability" to make the saccade toward the stimulus in the receptive field coded by the neuron compared to all other alternatives (Glimcher, 2014; Louie et al., 2011).

This model assumes that the response *R* to a stimulus *i*, is dependent on a ratio that takes into account the value of this stimulus (V_i) in relation to the value of all the stimuli present in the environment (a weighted sum of the values, ω, often considered as an average) at the time of the response selection (t_0, spatial context) and is also modulated by previous experiences or trials encountered so far (t -∞, temporal context). This temporal modulation of the context decays by exponentially weighting the order of each trial on a constant δ <1 in such a way that the further the trial is in time, the lower the weight (as a recency effect). This DN model can be simplified as followed:

$$R_t = \frac{V_i}{1 + \sum_{t=0}^{-\infty} \sum_i \delta^t \omega_i V_{i_t}} \quad (3)$$

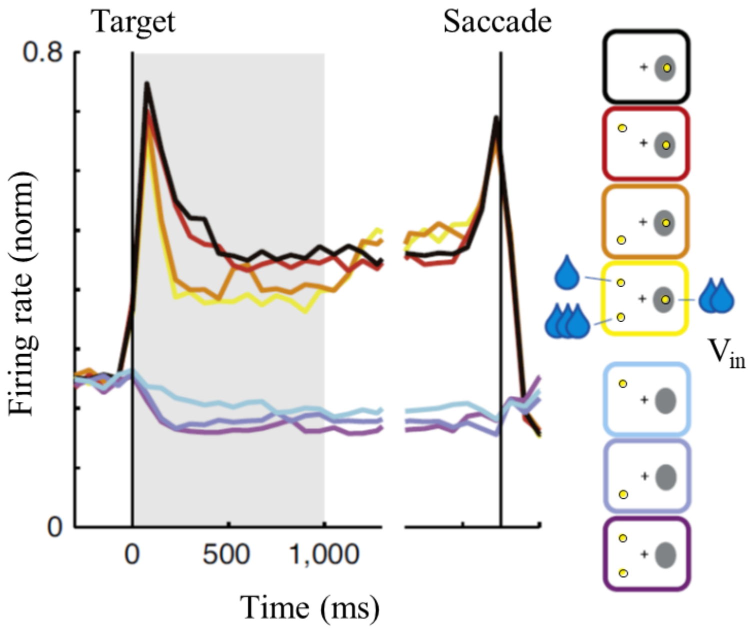

Fig. 12. Average firing rate of lateral intraparietal area from the appearance of the target(s) until the saccade as a function of the experimental context (colored screens represented on the right). The receptive field of the neurons is in grey, the yellow circles represent the targets and the blue drops represent the value of the stimulus reward (3 drops > 2 drops > 1 drop). The value of the target in the receptive field is constant but the firing rate of the neurons is dependent on the value of the other targets displayed during the trial. Adapted from (Louie et al., 2015).

Therefore, if the absolute value of one stimulus (V_i) is lower than the one of every other (the denominator), the response R when presenting all the stimuli (yellow screen; Fig. 12) will be lower than when presenting the stimulus alone (black screen), whereas R will be higher if V_i is larger than all the other stimuli's values (red screen). This model is very interesting, exhaustive and takes into account the temporal decay of the weight given to each stimulus. Furthermore, this formalization also applies to the (attractiveness) evaluation of FE (Furl, 2016). However, this model is difficult to implement because it has multiple free parameters. The main difficulty of having numerous free parameters is that it becomes possible to explain the same observation (R) via multiple solutions, thus becoming less generalizable.

II.2.2.3. Range-Frequency Model

The last model formalizing contrast effect on judgment that will be considered in this thesis is the one of Parducci's theory (1965), called the Range-Frequency (RF) model. As its name suggests, this model is based on the range principle and the frequency principle whose main parameters are the range and the rank. According to the range principle, the two extreme values of the stimuli encountered so far represent the boundaries of the context. The space inside of it is divided into subranges that are representative of the categories (or scale points) encountered during the judgment. The stimulus to be judged is placed according to the position of all other stimuli. The frequency principle takes into account the shape of the distribution (skewedness) of the different values of the context when judging the stimulus. Hence, in Parducci's example, squares which vary in size have to be categorized from "very small" to "very large". Individuals make their own "mental" reference of what is large and what is small, thus creating two categories within which they equally distribute the squares. But this equal distribution cannot occur if the frequency of the distribution is skewed; if there is twice as many large squares as small squares, according to the range principle, one third of the largest squares should be categorized as small. The RF model takes into account both principles that can be in conflict if considered together; each empirical limen ("psychological" threshold between two categories) is a weighted mean of range and frequency limens, a *compromise* between them and each stimulus is assigned to a specific rank. The *range* value of a stimulus (R_{ic}) can be mathematically captured by:

$$R_{ic} = \frac{(s_i - s_{min})}{(s_{max} - s_{min})} \tag{4}$$

where S_{min} and S_{max} are respectively the minimum and maximum values of the context when judging a stimulus i (S_i representing its objective value, outside of any context) in a context *c*. The *frequency* value can be captured by:

$$F_{ic} = \frac{(k_{ic} - 1)}{(N_c - 1)} \quad (5)$$

where k_{ic} is the rank of the stimulus i (S_i) in the context c and N_c is the number of stimuli in that context c. Hence, according to the range-frequency model an internal judgment J, of a stimulus i in a context c can be formulated as:

$$J_{ic} = w.R_{ic} + (1 - w).F_{ic} \quad (6)$$

where w [0; 1] is a relative weight that underlies the compromise between the range and the frequency principles. If $w = 1$, then individuals only consider the range principle and neglect the frequency principle. The opposite is observed if $w = 0$.

It is then possible to scale back the internal judgment, via a linear transform according to:

$$T_{ic} = a + b.J_{ic} \quad (7)$$

where T_{ic} is the rescaled rating of the stimulus *i,* in the context c, a, the minimum value of the scale and b, the range of possible ratings.

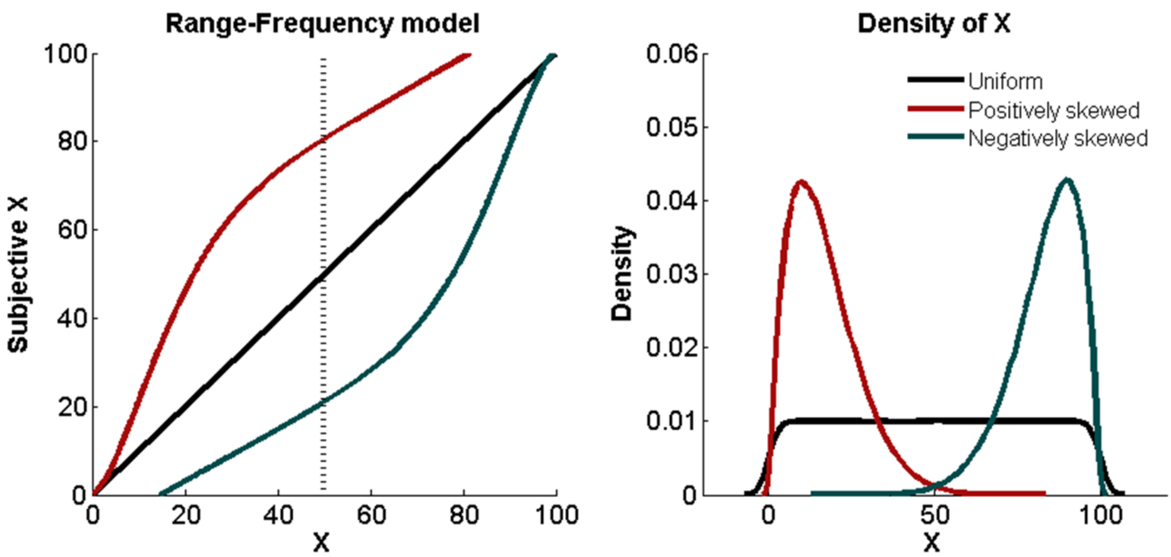

Fig. 13. ***Left panel:*** *Simulation of Equation (6) with w fixed at 0.5. Subjective values of the variable X as a function of their "objective" value and depending on their distribution (****Right Panel:*** *Uniform distribution in black, positively skewed in red and negatively skewed in green).*

A numerical example based on the simulation shown in Fig. 13 is developed in appendix 1. This model can easily be implemented because it only contains one free parameter (w) and has been applied to explain context effect on judgments such as physical attractiveness (Wedell et al., 1987) or happiness (Wedell & Parducci, 1988), research field in line with the present thesis. Furthermore, its free parameter (w) accounts for individual and experimental differences in the weight given to one principle (range or frequency) rather than the other. One limitation regarding this model is that, as we can see in the left panel of Fig. 13, the smallest (biggest) objective value must take the smallest (or biggest) subjective value of the scale (here 0 or100) whereas it is not always the case in ecological conditions. Moreover, this model does not seem to apply a dynamic weighting of the temporal context (progressive decline of the weight of contextual stimuli seen previously). On the contrary, each element constituting the context has the same weight, regardless of when it is presented.

II.2.3. Contrast or assimilation?

To sum up, assimilation effect seems to occur preferentially with a simultaneous presentation of the contextual stimuli and the target favoring an association between the two. For instance, when assessing the attractiveness of a target, Geiselman et al. (1984) only observed an assimilation effect when they presented pairs of faces, not when the faces were presented singly. This is also observed with simultaneous presentation of the neutral and the emotional stimuli during EC procedures (De Houwer et al., 2001). The assimilation effect was even stronger if participants were informed that the women to assess were friends (Geiselman et al., 1984; Wedell et al., 1987). However, simultaneous presentation of the target and the context can also lead to a contrast effect (Furl, 2016; Glimcher, 2014; Louie et al., 2011; Louie, Khaw, & Glimcher, 2013; Louie, Lofaro, Webb, & Glimcher, 2014). Furthermore, evaluative conditioning procedure, producing assimilation effect, can sometimes lead to contrast effect

(De Houwer et al., 1997; Unkelbach & Fiedler, 2016). Indeed, in one of the experiments of their meta-analysis, De Houwer et al. (1997) observed contrast effect during an EC procedure when using only two pairing (conditioning phase) during subliminal presentation of emotional words. This result comforts the importance of explicit association between the neutral and the emotional stimuli (US-CS statistical contingencies) for assimilation effect to be observed. Finally, Unkelbach & Fiedler (2016) observed that alternative forced-choice judgment between emotional and neutral FE before the conditioning phase (comparison in terms of liking between the emotional and the neutral FE) resulted in a contrastive encoding of the relation (Unkelbach & Fiedler, 2016). If the initial force-choice judgment was related to another concept, such as intellligence, classical assimilation effect was observed on neutral faces.

Martin et al. (1990) reported several factors modulating context effect. As presented before, the distribution of the contextual stimuli is important for the emergence of strong contrast effect (Parducci, 1965). A contrast effect is more likely to appear with extreme contextual stimuli (e.g., highly positive) whereas assimilation effect is more likely to appear with moderate contextual stimuli (Martin et al., 1990). Likewise, the likelihood of observing a contrast effect also seems to decrease with the number of categories presented to the participants (e.g., number of points in the scale). Therefore, comparison strategies, leading to a contrast effect, seems more likely to occur during an explicit judgment of the target (Kobylínska & Karwowska, 2014; Martin et al., 1990). However, this advantage seems to disappear with more complex tasks (e.g., during double tasks), suggesting that the contrast effect is more demanding in terms of cognitive resources (Kobylínska & Karwowska, 2014; Martin et al., 1990).

Among the different models presented, the RF model seems to be particularly relevant when only considering the contrast effect (Parducci, 1965). The mathematical formalization of this RF theory is stronger than the geometrical formalization of the model of Russell and Fehr (1987) but remains easy to implement and easily generalizable since it only includes one free parameter in comparison to the DN model (Louie et al., 2011). Furthermore, the mathematical formalization of the DN model is currently under debate (Gluth, Kern, Kortmann, & Vitali, 2020; Webb, Glimcher, & Louie, 2020).

II.2.4. Emotional context on space perception

Regarding the potential effect of emotional information of the context on distance perception (IPD and PPS):

- **If** the emotional context produces a change in the judgment of the valence of a neutral stimulus, regardless of direction of the effect (contrast or assimilation), and **if** the distance adjustment toward a stimulus (social or not) is dependent on the (positive-negative) valence of the stimulus, **then** changing the valence of a stimulus via the emotional context should lead to congruent distance adjustments (IPD and PPS).

Most of the studies conducted so far using contextual information (or information irrelevant for the task) were related to the effect of looming threatening stimuli on multisensory PPS representation (de Haan et al., 2016; Ferri et al., 2015; Taffou & Viaud-Delmon, 2014). In each study, authors observed an increase in PPS representation (with tactile perception used as a proxy of PPS evaluation) with threatening looming stimuli in comparison to neutral ones. However, it seems more likely that the effects observed were related to an increase in vigilance and anticipation of the threatening stimulus rather than an assimilation effect of the valence of the looming stimulus to the valence of the tactile stimulus. During an experiment using associative learning between an unpleasant/pleasant odor and a neutral visual stimulus, authors observed a shift of the visuospatial attention toward or away from the visual stimulus during a line bisection task (Rinaldi, Maggioni, Olivero, Maravita, & Girelli, 2018). More precisely, when lines to bisect were flanked with the visual (conditioned) stimuli, authors observed a shift of the estimated midpoint toward the visual stimulus associated with the pleasant odor and away from the stimulus associated with the unpleasant one. Finally, Tajadura-Jiménez et al. (2011) conducted an experiment during which participants listened to positive or negative music through headphones while performing an IPD judgments task (stop-distance paradigm). Authors observed a decreased in IPD when participants listened to positive music whereas it increased with negative music (Tajadura-Jiménez, Pantelidou, Rebacz, Västfjäll, & Tsakiris, 2011). However, in this experiment, valence ratings were only performed on the music and not on the confederates. Therefore, we are unable to conclude whether the IPD adjustment was relative to the change in the valence of the confederate produced by the valence of the context or only due to the change in the emotional state of the participants induced by the valence of the music.

To conclude, although FE of emotion have a universal basis, their recognition and their perceived intensity depend on the emotional context in which they are presented. This can lead to contrast or assimilation effects of contextual information on the judgment of the target. The assimilation effect seems to be more likely to occur when implicitly suggested by the task design (e.g., temporal or spatial contiguity or strong statistical contingencies between the emotional stimulus and the neutral one), favoring an associative link between the two. The contrast effect (comparison between the target and the context), seems to be automatically set up as soon as the presentation of the target is disentangled from that of the contextual stimuli. However, the emergence of this effect depends on the mental load triggered by the task. Several models are proposed in order to capture as well as possible these effects of the context, helping us to categorize them either as contrast effect or as assimilation effect.

So far, we know that IPD adjustment is dependent on the emotional FE of others but whether changing the valence of a neutral FE through emotional information of the context changes IPD adjustment remains an open issue. If IPD adjustment to a neutral stimulus is sensitive to change in valence produced by the emotional context, the RF model should be able to capture it.

In the next and last section of this introduction, we will present the different brain structures involved in the perception and the evaluation of the emotional FE. We will also present the bodily (physiological) changes resulting from the perception of FE and how these electrophysiological responses can be sensitive to the proximity of others. Indeed, electrophysiological responses are part of an emotional episode just as emotional feeling (Scherer, 2005). They are automatic, difficult to falsify and, thus offer an appealing method to gather quantitative information of the emotional response.

III. FE PERCEPTION: WHAT HAPPENS IN THE BODY?

When facing an emotional stimulus, and in particular an emotional FE, specific cerebral and physiological responses occur. The importance of the neurophysiological responses to emotion was already highlighted by early accounts of James (1884) and Cannon (1927); it is now recognized as a full-fledged component of an emotional episode (Scherer, 2005). As described earlier, the detection and the processing of emotional information, including others' FE, is particularly important in terms of survival (Darwin, 1872; Ekman, 1980). It may thus not be surprising that this information is subject to specific cerebral treatment at both cortical and subcortical levels. This cerebral treatment contributes to the preparation of the whole body in the elaboration of the most appropriate response to the specific emotional situation (LeDoux, 1998).

If I see someone angry looking at me, my brain will process the emotional information with two parallel roads: at the subcortical level, a first, fast, rough processing of the emotional information will allow to prepare a quick reaction of the body; at the cortical level, a slower, more detailed processing of the emotional information, involving the conceptual knowledge, will allow to put this emotional situation in perspective and modulate the emotional response (Fig. 14). Thus, the nervous system is responsible for both the initiation of appropriate actions in response to the environment and their regulation (Jänig, 2006). At the body level, the emotional information produces physiological arousal which allows an automatic motor preparation adapted to the emotional event.

Since the aforementioned individual seems threatening, my body is preparing to react accordingly. In case he/she tries to attack me, I need to be ready to fight or to flight. I need to be ready to run fast so I need more oxygen in my muscles, I have to be light and I must not slip off the different surfaces that I am going to lean on while I am running etc. (Jänig, 2006). If nothing happens, great, but at least my body would have been ready.

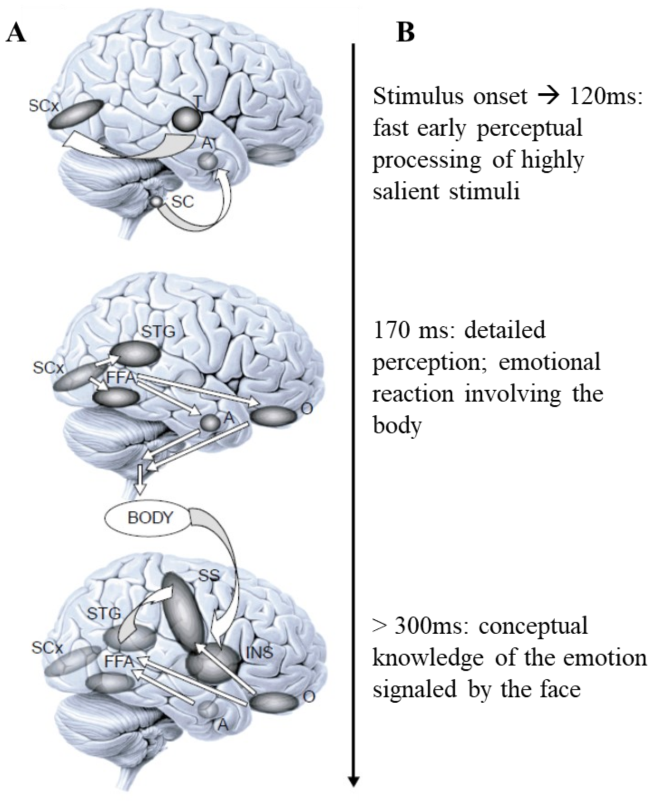

Fig. 14. Processing of emotional FE as a function of time. ***A*** *Structures involved in emotion recognition at various time points. A, amygdala; FFA, fusiform face area; INS, insula; O, orbitofrontal cortex; SC, superior colliculus; SCx, striate cortex; SS, somatosensory cortex; STG, superior temporal gyrus; T, thalamus.* ***B*** *Time course of emotion recognition, from the onset of the stimulus at the top, through perception to final recognition of the emotion at the bottom. Attempts to localize the perception/recognition of the stimulus in space or in time suffer from the fact that the same brain structures participate in different components of processing at different points in time. From Adolphs, 2002.*

In this section, we will limit ourselves to presenting the different cerebral and physiological responses produced during the perception of emotional stimuli and in particular to emotional FE. We will also present how these reactions are potentiated by the proximity of the emotional stimulus.

III.1. Central nervous system

Although in the past some authors have focused on finding the site of emotions in the brain (Maclean, 1949; MacLean, 1980), it is now well accepted that the processing of emotional information is widely distributed (Adolphs, 2002a, 2002b; Palermo & Rhodes, 2007). In fact, cerebral activity is way more complex and the simplest cognitive act implies multiple networks that are built on trade-offs between spatial and anatomical costs and benefits (Bullmore & Sporns, 2012). More precisely, and as presented in Fig. 14, the perception of emotional FE leads to the activation of multiple cortical as well as subcortical structures (Adolphs, 2002a, 2002b; Gil, 2018; LeDoux, 1998; Mcfadyen et al., 2017; Palermo & Rhodes, 2007).

The subcortical structures process rapidly and coarsely the emotional information while the cortical structures, slower, have a more refine processing of the information of the face and rely on more explicit treatment, which includes, for example, the retrieval of semantic knowledge about the FE (Johnson, 2005; LeDoux, 1998, 2003; Mcfadyen et al., 2017; Vuilleumier, Armony, Driver, & Dolan, 2003). These two types of structures communicate with each other, in particular via the amygdala.

The amygdala, is thought to be particularly central in emotional processing because it is thought to be the integration site of the emotional component of the sensory inputs. It receives and sends inputs from both the other subcortical structures and the cortical structures of the brain (Gil, 2018). At the subcortical level, the amygdala receives inputs from the *thalamus*, involved in the sensory processing (LeDoux, 1998; Morris, DeGelder, Weiskrantz, & Dolan, 2001; Palermo & Rhodes, 2007; Vuilleumier et al., 2002). It projects to the *hippocampus,* responsible for the declarative memory component associated with the displayed emotion and is more generally involved in the recall of emotional events. This relation between those two structures seems to be necessary to learn new emotional associations (LeDoux, 1998). The amygdala also sends input to the *hypothalamus* (involved in the neurovegetative and neuroendocrine responses) which contributes to the emotional response of the body (sympathetic activation, Jänig, 2006). Amygdala's activity increases during the perception of fearful stimuli (Larson et al., 2006) as well as during the perception of negative FE, be it conscious or not (Morris et al., 2001; Whalen et al., 1998, 2001). Even more convincing, patients with amygdala lesions have deficits in FE recognition (Adolphs, Tranel, Damasio, & Damasio, 1994; Williams et al., 2001) and in the experience of fear (Feinstein, Adolphs, Damasio, & Tranel, 2011). As a piece of evidence, patient S.M. suffering from a bilateral destruction of the amygdala showed deficit in recognizing FE of fear (Adolphs et al., 1994).

Emotional FE are also processed at the cortical level. The *occipital cortex* processes visual information (for visual stimuli) and this processing extends via both ventral and dorsal areas (Adolphs, 2002b). For instance, the activity of the *right fusiform area* (in the inferior temporal cortex), known to be involved in the perception of the spatial configuration of the face (Barton, Press, Keenan, & O'connor, 2002) increases when perceiving fearful FE in comparison to neutral ones (Vuilleumier, Armony, Driver, & Dolan, 2001). Furthermore, the *superior temporal sulcus* also seems to be involved in the identification of emotional FE and in particular in moving FE (Sliwinska & Pitcher, 2018; Zhang et al., 2016). Indeed, TMS over the left and even more over the right superior temporal sulcus impairs the recognition of animated FE (Sliwinska & Pitcher, 2018).

The prefrontal cortex, especially implicated in planification and decision making, is also thought to be implied in the adjustment of emotional response (Gil, 2018). The *orbitofrontal* cortex contributes to the recognition of emotional FE, in particular through its relation with other areas involved upstream in the emotional processing. Indeed, its relation with the amygdala, but also temporal regions, contributes to the recognition of emotional FE (Adolphs, 2002b; Iidaka et al., 2001; M. L. Willis, McGrillen, Palermo, & Miller, 2014). Furthermore, the *medial prefrontal cortex*, also seems to be wildly involved in the emotional processing of FE and especially in its relation with the amygdala (Vieira et al., 2019; Willinger et al., 2019). Furthermore, the frontal cortex would be involved in two pathways; one related to the implicit emotional processing: the amygdala-medial frontal pathway whose activation would be directly correlated with that of the arousal system and a pathway related to the explicit emotional processing: the hippocampus-lateral frontal (Bechara et al., 1995; LeDoux, 1998; Williams et al., 2001).

Finally, and as presented above, the cortical areas involved in the cortical pathway, through their interaction with the amygdala and the thalamus projecting to the hypothalamus, also contribute to the response of the autonomic nervous system to emotional FE via the arousal system.

III.2. Autonomic nervous system

As aforementioned, bodily changes seem to be a necessary component of an emotional reaction (Scherer, 2005). These bodily changes depend on the activity of the autonomic nervous system (ANS). The ANS is involved in allostasis (maintain of the internal milieu stable during bodily or environmental changes) and in the "generation of behavior". It is divided in three parts: the enteric, the parasympathetic and the sympathetic division (Jänig, 2006). The last two divisions receive information from the preganglionic neurons (starting either in the spinal cord or in the brain stem) and innervate target organs through postganglionic neurons (Fig. 15, dotted lines).

Traditionally, the parasympathetic and the sympathetic nervous systems (SNS) are often considered to have opposite functions: the parasympathetic division is mainly associated with "rest and digest" functions whereas the sympathetic system is mainly related to the "fight and flight" tendency and physiological arousal (excitement, Fig. 15). Thus, during situations requiring physiological arousal and implying an action tendency (e.g., perceiving a threat as presented in the introduction part of this section), the SNS is automatically activated while the parasympathetic activity is suppressed. The activation of the SNS results, among other things, in an increased heart rate, the vasoconstriction of arteries, an increased sudomotor nerve activity (leading to an increase in the eccrine sweat glands activity), the relaxation of the urinary bladder, a mydriasis and a congruent thermoregulation (Jänig, 2006). The purpose of these changes in the body is to prepare the body to react in the most appropriate way to the elements of the environment. Thus, the ANS is sensitive to the signals sent from the brain when perceiving an emotional stimulus and to the cognitive activity related to this perception (Jänig, 2006). While specific emotional experience can trigger specific cerebral activation (LeDoux, 1998), the autonomic activations are quite uniform from one emotion to another because related to the arousal and not to the valence of the emotional episode (Cannon, 1927).

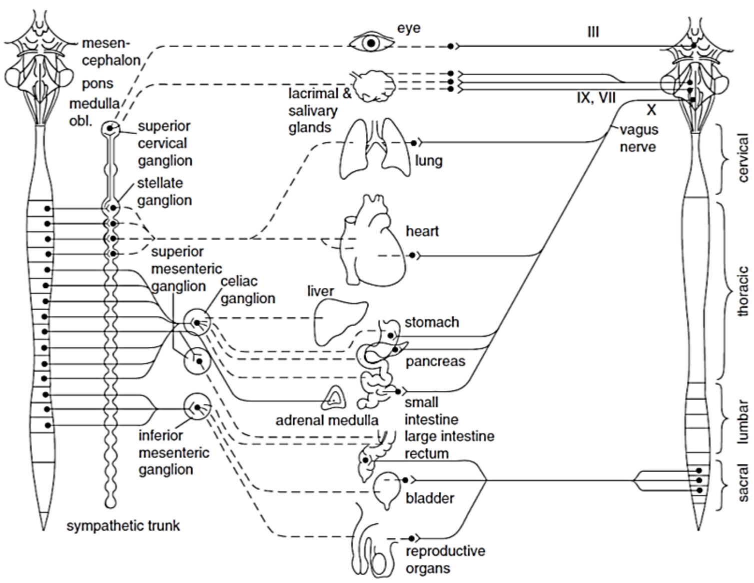

Fig. 15. Sympathetic ***(left part)*** *and parasympathetic nervous system* ***(right part)****. Solid lines represent the preganglionic axons and the dotted lines, the postganglionic axons. From Jänig (2006).*

Perceiving stimuli with an emotional content leads to an increase in pupillary diameter (Aboyoun & Dabbs, 1998; M. M. Bradley, Miccoli, Escrig, & Lang, 2008; Hess & Polt, 1960), regardless of the sensory modality of the stimulus (Partala & Surakka, 2003) to facial thermal variations (Kosonogov et al., 2017), a heart rate increase (Appelhans & Luecken, 2006) and electrodermal changes (Boucsein, 2012). These changes are thought to be associated with motor preparation to physical reaction to stimuli and their intensity is dependent on the level of arousal triggered by the stimulus.

The perception of body signals of others, such as their FE, also triggers physiological activation associated with an increase in the activity of the sympathetic division of the ANS (Hopkins, Dywan, & Segalowitz, 2002; Kret, Roelofs, Stekelenburg, & de Gelder, 2013; Williams et al., 2005). As explained earlier, those facial signals inform about the emotional state of others and, when facing an emotional situation, the body automatically prepares to react accordingly. Furthermore, others' proximity can lead to discomfort (Hayduk, 1978; Lloyd, 2009; Sommer, 1959). This physical proximity would be associated with an increase in physiological arousal (Aiello, DeRisi, Epstein, & Karlin, 1977; McBride, King, & James, 1965; Wilcox, Allison, Elfassy, & Grelik, 2006). Therefore, proximity to an individual with an emotional FE, and in particular a threatening one, should lead to an even stronger sympathetic response.

Therefore, perceiving emotional FE seems to lead to specific cerebral responses, depending on the perceived emotion, and physiological responses implicated in the motor preparation. These responses (physiological and cerebral) are thought to be interconnected in order to evaluate as well as possible the emotional situation depending on our knowledge and on these responses.

III.3. Threat perception

Threat perception and in particular the perception of emotional FE related to threat (FE of fear or anger) has been particularly studied. Threatening stimuli trigger specific cerebral activation and strong ANS responses because they are part of the most relevant cues for survival (LeDoux, 1998, 2000, 2003; Öhman & Dimberg, 1978). According to LeDoux (1998), the perception of threatening stimuli is thought to be underlined by the “fear system” dedicated to danger detection and to the identification of the most appropriate behavior to engage in order to maximize the chances of survival. Hence, during a conditioning procedure, when a neutral stimulus (CS) is associated with a negative stimulus (US) such as an electrical shock, the appearance of the neutral stimulus triggers an increase in the physiological response when compared to the presentation of the same neutral stimulus before the conditioning phase. This physiological response usually decreases gradually when the appearance of the neutral stimulus is not followed by the electrical shock anymore (extinction phase) which highlights the plasticity of the brain related to the processing of threat stimuli. However, Öhman & Dimberg (1978) revealed that conditioned angry faces (associated with an electrical shock) were more resistant to extinction in comparison to neutral or happy conditioned faces (Esteves, Dimberg, & Öhman, 1994). According to the authors, negative FE, are more likely to be associated with potentially threatening and hazardous events from an evolutionary point of view. Therefore, if a response is conditioned to a stimulus that is likely to produce this type of response naturally, then this response to that stimulus is harder to extinguish.

As presented earlier, emotional stimuli, including threatening FE, would be processed simultaneously by two neural systems: the amygdala-medial frontal network (for the implicit emotional processing) and the hippocampus-lateral frontal one (for the explicit emotional processing; Bechara et al., 1995; LeDoux, 1998; Williams et al., 2001). The amygdala-related pathway activation would occur together with the activation of the arousal system (the sympathetic nervous system), expressed by phasic electrodermal responses, and the recruitment of motor areas (Williams et al., 2001). This simultaneous activation of the sympathetic system early in the treatment of the emotional FE would contribute to rapid motor preparation in relation to defense mechanisms (Boucsein, 2012; LeDoux, 1998). Thus, perception of threatening FE would automatically trigger defensive mechanisms that can be seen at both the central and the peripheral levels. Furthermore, physiological responses can also be observed during unconscious presentation of emotional stimuli (Almeida, Pajtas, Mahon, Nakayama, & Caramazza, 2013; LeDoux, 1998; Öhman & Soares, 1994; Silvert, Delplanque, Bouwalerh, Verpoort, & Sequeira, 2004; Tamietto et al., 2009). This response to subliminal presentation corroborates the sympathetic activation directly from the subcortical pathway favoring fast and automatic motor preparation, a very low-level response. These emotional related responses could thus occur in the absence of conscious perception of the stimulus and allow the body to prepare to react to the threat in the most appropriate way if the brain, through appraisal of the situation, considers that a defensive behavior is needed vis-à-vis this stimulus.

Distance also influences threat perception. As observed in animals, the proximity of a predator leads to fight or flight behaviors (Blanchard & Blanchard, 1989; Hediger, 1968). In human, when perceiving a close threat, such as a needle, the sympathetic nervous system is recruited and the electrodermal response increases (Rossetti, Romano, Bolognini, & Maravita, 2015). The same applies for IPD. This natural distance between individuals is often seen as a safety margin between the self and others, necessary for insuring both appropriate interactions and physical integrity (Lloyd, 2009; Ruggiero et al., 2017). As introduced in section I.4, a too short IPD triggers discomfort and can be viewed as a threatening situation. In addition of being in a situation evaluated negatively, the discomfort generated by this situation could also be observed through physiological changes. Individuals' proximity would lead to heart-rate changes (Wieser, Pauli, Grosseibl, Molzow, & Mühlberger, 2010), to an increase in cortisol level, an hormone related to stress (Evans & Wener, 2007), and to an increase in the electrodermal activity (Aiello et al., 1977; McBride et al., 1965; Wilcox et al., 2006), even more if they are threatening (Ellena, Battaglia, & Làdavas, 2020). At the cerebral level, Kennedy and colleagues (2009) revealed that a violation of IPD in healthy participants leads to a bilateral activation of the amygdala. Furthermore, in case of bilateral lesion of the amygdala, people reduce atypically their IPD (Kennedy et al., 2009). Hence, the amygdala also seems strongly involved in IPD regulation and in particular in the processing emotional response related to IPD violation. Furthermore, fronto-parietal areas as well as the premotor cortex, involved in PPS perception were found to be activated with approaching social stimuli (Lloyd, 2009; Vieira et al., 2019). Approaching social stimuli also elicited the activation of the periaqueductal grey, involved in defense mechanisms (Vieira et al., 2019). Lloyd and Morrison (2008) also found a stronger activation of the temporo-occipital areas, involved in spatial processing, when observing social scenes with a threatening individual. Furthermore, the amygdala (Kennedy et al., 2009), the dorsal anterior cingulate cortex and the insula whose activation is related to emotional response are more activated by stimuli that are within rather than outside of the PPS (Vieira et al., 2019).

Taken together, those results suggest that proximity of individuals, and especially a threatening one, leads to cerebral activation related to PPS perception and to emotional processing. Mixing these two factors (emotional and spatial) potentiates the cerebral responses and the bodily changes related to motor preparation. At the behavioral level, avoidance strategies can be observed leading in particular to increased IPD.

As a whole, it seems that IPD is built on sensorimotor representations but that its adjustment is strongly dependent on defense mechanisms related to threat perception. This way, PPS can be seen as a no-go zone during social interaction. The presence of others within PPS triggers strong response from the whole body. Those responses should be even stronger with threatening stimuli. In order to maintain homeostasis (assuring maintenance of physiological parameters at a specific level, Jänig, 2006) during social interaction, individual would therefore automatically adjust IPD depending on the level of threat of the other (i.e., in order to maintain PPS unviolated plus a margin of safety relative the potential threat of the conspecific).

RATIONALE OF THE THESIS

Through this introduction, we have seen that:

- PPS is a multisensory interface between the body and the environment in which we can interact with the elements that compose it
- PPS representation is relative rather than absolute. It is dependent on our action capacities, object values, but also on defense mechanisms
- IPD seems to be built on PPS representation but its adjustment is specifically dependent on social factors
- The affective valence of a stimulus can be dependent on the emotional context in which it is presented
- The affective valence of a stimulus, especially if negative (threatening), modifies our cerebral and physiological responses. As the detection of these stimuli is of paramount importance for our physical integrity, our body prepares itself to react congruently with the valence of the stimulus it is confronted to, in line with approach-avoidance strategies
- The intensity of these cerebral and physiological responses increases with the intensity of the affective value of the stimuli
- The intensity of these cerebral and physiological responses to threatening stimuli increases with its proximity.

In the following part of this thesis, we focused on two main questions that remained unanswered (Fig. 16):

- **If** the physiological responses to individuals depends on the level of threat they suggest and that this response is potentiated when they are within the PPS and **if** IPD adjustment, whose basis is built on PPS, depends on the level of threat suggested by the individuals **then,** there should be a relation between the intensity of the physiological response to individuals in the PPS and the adjustment of IPD with these individuals.

- **If** emotional information from the context can alter our emotional judgment (affective value) regarding individuals and **if** IPD adjustment is dependent on the affective value attributed to individuals **then,** the emotional context should lead to IPD adjustment in relation to the changes in emotional judgment.

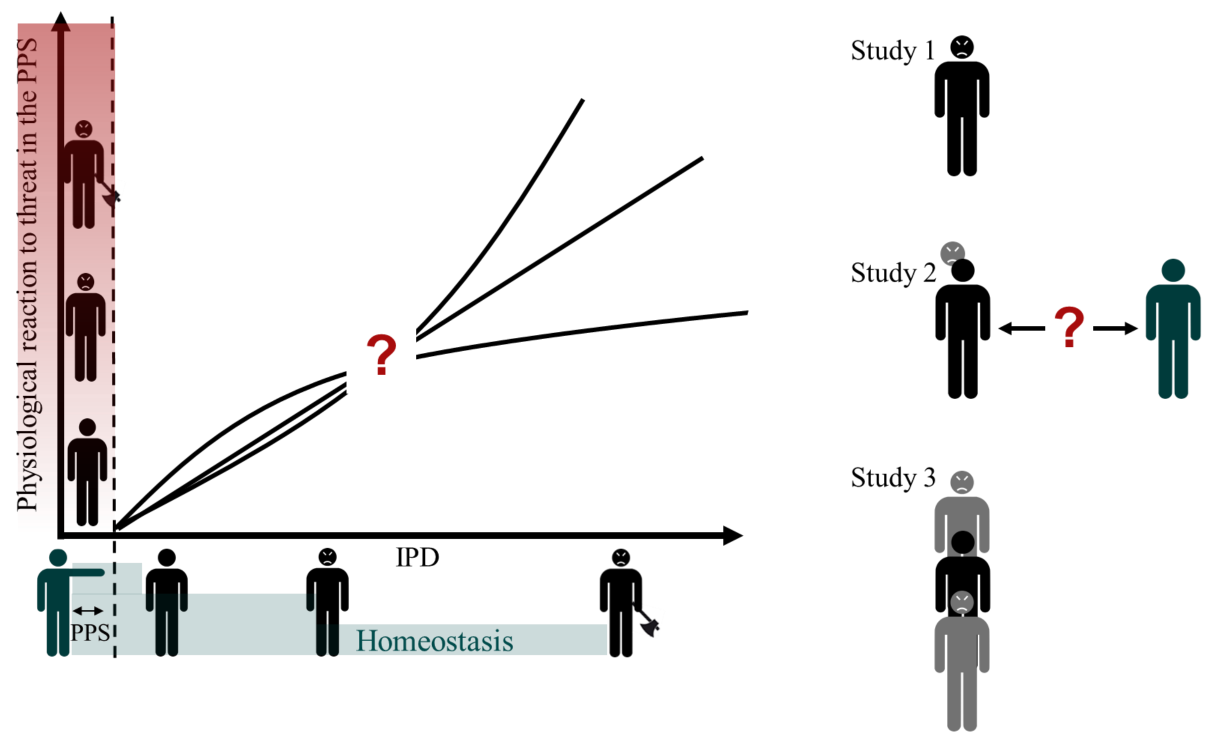

Fig. 16. Schematic illustration of the two main questions of the thesis (red question marks). Green individuals represent the observer; black ones represent the target and the grey ones represent the emotional context. The degree of threat is schematized by: no face: neutral stimuli (no threat); angry face: moderate threat; angry face with an axe: high threat. ***Left panel****: Is there a relation between IPD adjustment (x-axis) and the physiological response to a threatening stimulus within the PPS (y-axis, the origin representing the position of the observer, in green)? The dashed line represents the observer's PPS. The red banner represents the increasing physiological response. The green banners (bottom) represent the minimum IPD in order to maintain homeostasis. The axes of the graph are inverted in order to observe a horizontal representation of IPD.* ***Right panel****: What is the effect of the emotional context on IPD adjustment? Not to scale.*

In order to test these hypotheses, we first decided to investigate whether the physiological response triggered during the perception of confederates with various emotional FE in the PPS predicts the adjustment of IPD with these confederates (Study 1). To do so, we used the phasic electrodermal response as a proxy of threat perception within the PPS. If a confederate is threatening (i.e., a neutral point-light display with an angry facial expression), the IPD and the physiological response to its perception when displayed within the PPS should be larger than with a non-threatening confederate. Hence, the increase in one of the two responses should be linked to the increase in the other.

Secondly (Study 2), we investigated whether the same effects could be observed when presenting the emotional information (i.e., FE) at the perceptual threshold just before the appearance of a neutral confederate. In everyday life, we often do not perceive all the emotional information of individuals around us. We only surreptitiously glimpse their FE. Thus, presenting FE at the perceptual threshold offers a relatively ecological situation. If the presentation of an emotional FE (angry, happy or neutral) at the perceptual threshold can be associated with the subsequent presentation of neutral confederate, we should observe an IPD adjustment with the confederate congruent with the FE. We should also observe increased physiological response to the neutral confederate violating IPD if associated with an angry FE.

Third, we were interested in the effect of the emotional context on IPD adjustment. We conducted a third study (Study 3) during which we created an emotional context by presenting singly virtual characters with an angry or a happy FE (contextual characters) and characters with a neutral FE (targets). Then, the effect of the context was first assessed through valence judgments of the characters, then through IPD judgment. With this experimental procedure, we should observe a congruent effect of the emotional context on IPD adjustment and the subjective evaluation of the valence reflecting a contrast effect, as predicted by the RF theory.

The last study presented (Study 4), conducted during the Covid-19 lockdown is a direct application of the researches we conduced so far. This study allowed us to investigate to what extent the presence of a “protective” object (a face mask) could alter IPD adjustment (in comparison to the known effects of emotional FE on IPD adjustment). Indeed, before the end of the lockdown, wearing a face mask was not mandatory and it could be seen as a potential proof of illness or vulnerability toward the virus or it could be seen as a protection for yourself, as a civic act.

EXPERIMENTAL

SECTION

GENERAL METHOD

In this section, we will present the general method and the tools used in the different studies developed in this thesis. However, it is important to note that, due to the lockdown and the current health conditions, two of the planned experiments had to be set aside. They were thus replaced by two online experiments in order to adapt our research as best as possible to this period. Thus, half of the experiments reported here is based on a paradigm associating physiological recording during the presentation of human-like stimuli in a virtual environment and the assessment of preferred IPD with the same stimuli (Study 1 and 2). The other half (Study 3 and 4) is based on online assessment of IPD with virtual characters. The virtual characters used in those two last experiments are part of the database we designed. The database is detailed in appendix 2 (preprint available online).

Virtual reality and human-like stimuli

Material

In Study 1 and 2, we decided to use Virtual Reality (VR) because it has the advantage of being closer to realistic and ecologic situations while allowing a strong experimental control. In addition, the immersive properties of VR are particularly valuable when studying social interaction (Blascovich et al., 2002; Loomis, Blascovich, & Beall, 1999). Indeed, even with simplistic virtual characters, participants can infer a feeling of social presence and the experimental results obtained in VR using virtual characters are consistent with the ones observed in real-life social situations. It is therefore a particularly valuable tool for studying IPD adjustment (Bailenson, Blascovich, Beall, & Loomis, 2003; Blascovich et al., 2002). VR systems are often associated with immersive headset but other systems of projections such as stereoscopic ones are also part of it.

Stimuli

For two of our studies, we used a 4 m x 2 m screen with a 4 K spatial resolution (3840 × 2060 pixels) on which visual stimuli were rear projected with a stereoscopic video projector (120 Hz, Christie Mirage 4K25 DLP 3D projector). Distance and stimuli's 3D perception were allowed by the use of active 3D eyewear. The generation of the stimuli was calibrated to the participants' height and inter-pupillary distance. Thus, each eye alternatively saw a specific image of the same stimulus which allowed its 3D perception (60 images per second per eye, Fig. 17).

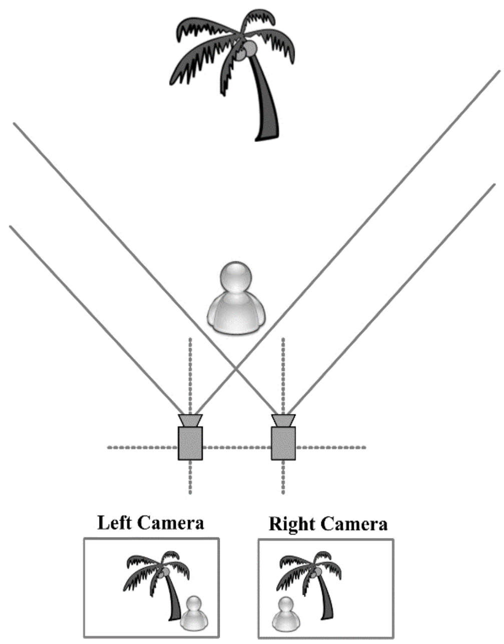

Fig. 17. Schema of stereoscopic perception. Two different images of the same scene are recorded with a specific point of view (as in binocular vision). Then, the image taken with the left (right) camera is sent to the left (right) eye, recreating the 3D perception

The human-like stimuli we used consisted of point-light displays (PLD) corresponding to schematic representation of the body of adult males or females (Johansson, 1973). The walking PLD were created by Mouta et al. (2012), but we set up the oscillating ones (Study 1, task 1). For every PLD, the body motions of adult models were recorded using a motion capture system while infrared markers were positioned over their head, both shoulders, elbows, wrists, hips, knees and ankles. Then, the dots representing markers' position were redesigned and resized (54 cd/m2, Fig. 18) and a loop of the motion sequence of interest was created (i.e., walking sequence). The main interest of this type of stimuli is that they keep all pieces of information related to movements (e.g., gait, distance, motion, etc.) while removing other non-motor pieces of information (e.g., age, dressing style etc., Iachini et al., 2016) that can affect IPD adjustment.

Participants stood up at 1m from the screen. The walking PLD started from the left or the right side of the participants, walked toward them at a constant speed of 1.2 m/s and crossed them at different inter-shoulder distances (varying from collision to very large distance) before disappearing (Fig. 18.B). Oscillating PLD were presented moving in place but without displacement in space (as if they were standing in line) at different distances from the participants (in the PPS, at the limit of reachability or in the extrapersonal space of participants, Fig. 18.A). This oscillation allowed 3D perception and thus, depth and distance perception while keeping the PLD at a constant distance from participants.

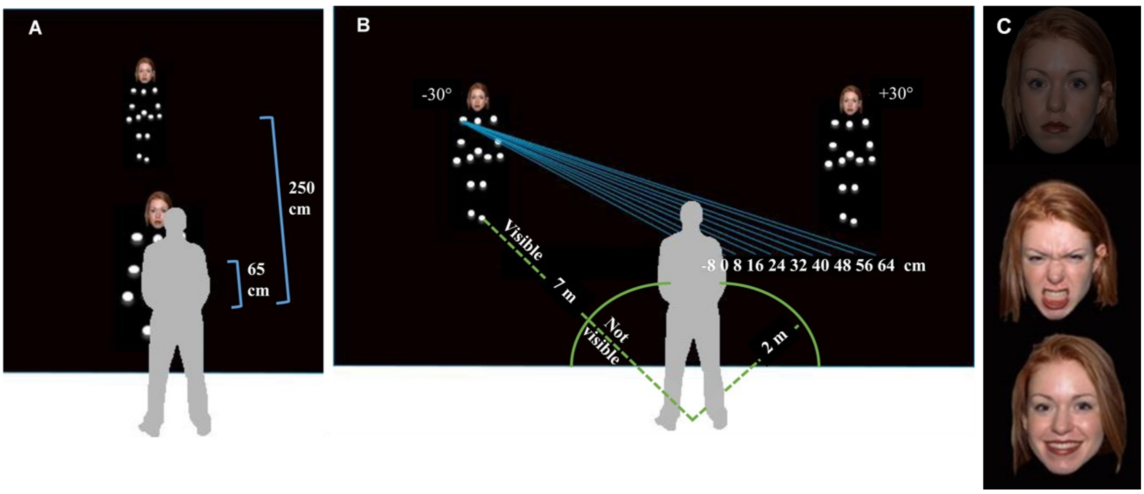

Fig. 18. ***A***: *location of PLD during the reachability judgment task (Study 1, task 1). Participant were placed in front of the screen; their EDA was recorded while they performed a reachability judgment task.* ***B***: *schematic representation of interpersonal distance judgment task (Study 1, task 2 but task 1 and 2 of tudy 2 are very similar). In Study 2, the actor's face appeared at the perceptual threshold before the appearance of the PLD.* ***C***: *Illustration of the facial expressions used in Study 1 and 2. In Study 2, the luminance of the faces differed for each participant (individual threshold).*

The affective valence of the social stimuli was conveyed by pictures of the face of male and female actors with different FE (neutral, happy or angry, Fig. 18.C) taken from the NimStim database (Tottenham et al., 2009). For the purpose of our experiments, we removed the neck and the background on every picture to incorporate them into the scene. The pictures could be directly positioned at the level of the PLD's head (Study 1) or briefly presented just before the appearance of the PLD at the level of their head position (Study 2). In both studies, each participant saw several actors but each actor displayed one FE only. The assignment of an actor to a specific FE was pseudo-randomized from one participant to the other.

Physiological recording: Electrodermal activity

Before selecting the electrodermal activity (EDA) as the marker of physiological change in our experiments, we also considered the high frequency heart rate variability (HF-HRV, appendix 3) and pupillary dilatation (studies not reported). Both are known to be sensitive to the emotional load conveyed by others facial expressions (Park, Van Bavel, Vasey, & Thayer, 2013; Tamietto et al., 2009). A decrease in HF-HRV reflects a suppression of the parasympathetic nervous system activity; and the pupillary dilation reflecting the physiological arousal and the mental load, is regulated by the sympathetic branch (M. M. Bradley et al., 2008; Chen, Calvo, Nourbakhsh, & Wang, 2015; Hot & Delplanque, 2013). We chose EDA because HF-HRV analysis requires a recording of the same emotional content between 1 and 5 minutes (Malik, 1996), which is not the best design for our experimental paradigms and because our stereoscopic equipment was hardly compatible with pupillometry recording.

EDA is a physiological response that reflects the eccrine sweat glands activity that are strictly innervated by the sympathetic nervous system. Thus EDA reflects physiological arousal (Boucsein, 2012). It corresponds to changes in the electrical resistance of the skin's surface due to sweat liberation from the eccrine sweat glands produced by the sudomotor nerve's activation (Fig. 19, top panel). The sweat that is released produces a reduction of the skin resistance, leading to an increase in the skin conductance (SC, Fig. 19, central panel). The EDA can be divided into two type of responses: a *phasic response* corresponding to pics (wavelets on the SC response, Fig. 19, central panel), produced by the perception of stimuli and a *tonic response* that corresponds to slow changes of the general level of the electrodermal signal, mostly related to the general arousal. From every electrodermal index available, we used the phasic driver (Fig. 19, bottom panel) which corresponds to the phasic response freed from the tonic level, including sweat evaporation (Benedek & Kaernbach, 2010a, 2010b). More precisely, the phasic driver comes from a nonnegative deconvolution (or signal decomposition) of the raw electrodermal signal into a tonic and a phasic component and reflects the activation of the sudomotor nerve; it is thus the integral between the tonic and the phasic curves. Through this procedure, it is possible to recover a signal close to the one of the sudomotor nerves. Furthermore, this procedure makes possible to detect pics that would be undetected with classical method due to the slow evaporation of the sweat hiding them or to have a precise idea of the amplitude of the pics because freed from the tonic level.

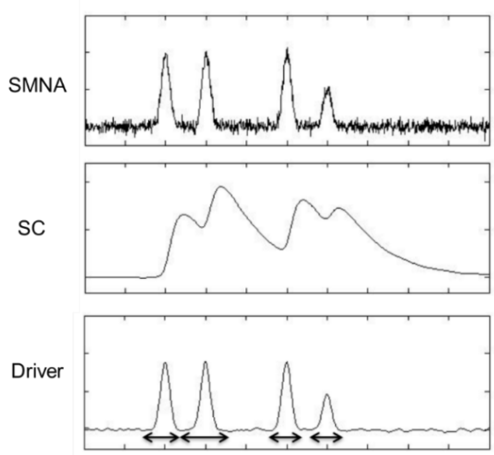

Fig. 19. Example of deconvolution of the electrodermal signal. ***Top panel****: sudomotor nerve activity (SMNA) following the stimulus' presentation.* ***Central panel****: Electrodermal response to the stimulus' presentation producing skin conductance (SC) changes.* ***Bottom panel****: Phasic driver computed from the deconvolution of the SC response. Retrieved from http://www.ledalab.de/documentation.htm*

Electrodermal signal was recorded during the first task of Study 1 and 2 in order to obtain the stronger responses related to stimuli presentation. Indeed, the signal decreases with habituation. During these tasks, PLD were presented either close to the participant (within PPS in Study 1, Fig. 18.A, and colliding participant's shoulder in Study 2), far from the participant (in the extrapersonal space or crossing him/her at the largest inter-shoulder distance), or at the limit of reachability (using fillers in Study 1) or at the average IPD established from Study 1 (in Study 2). The period of interest for the EDA recording was from 0.5 sec to 6.5 sec (in Study 1) and 5.5 sec (in Study 2) following the stimuli appearance which corresponds to the duration of stimulus presentation (either moving stationary in Study 1 or approaching the participant in Study 2).

Experimental task: interpersonal distance judgment

Method of constant stimuli

In each of our study, we used an IPD judgment task in order to determine IPD, either with the stimuli crossing participants (Study 1 and 2) or with the stimuli being motionless in front of them (Study 3 and 4). Participants had to estimate whether the distance between themselves and the stimulus was appropriate (or whether the crossing distance was comfortable, response "yes") or not (response "no") for social interaction. The psychophysics method used was the one known as the "method of the constant stimuli". This method consists in randomly presenting several times the stimuli at different (crossing) distances from the participants varying from very close to very far. For each trial, participants provide a binary response ("yes" = 1; "no" = 0).

In Study 1 and 2 (Fig. 18.B), the walking PLD appeared either on the left or the right side of participants at a distance of 6.5 m or 7 m from participants, walked toward them and disappeared at 1.5 or 2 m (for Study 2 and 1 respectively) from them. At their disappearance, participants estimated whether the crossing distance (when both shoulders would have been at the same level) was comfortable or not.

In Study 3 and 4 (Fig. 20), the motionless characters appeared in an empty room (both created on Unity) at different distances from the proximal side of the room according to the participants position (varying from 25 cm to 135 cm in Study 3 and from 28 to 140 cm in Study 4). Participants had to imagine themselves at the forefront of the scene, and had to estimate whether the distance between themselves and the character was appropriate for social interaction or not.

Fig. 20. Schematic representation of interpersonal distance judgment task in Study 3 and 4. The characters appear at the participant's screen and stays until participants provide their "appropriate" "not appropriate" response.

Statistical estimation of IPD

From the binary ("yes" = 1; "no" = 0) responses obtained during the IPD judgment task, we used a logistic regression, to compute the inflexion point corresponding to the transition between "no" (i.e., inappropriate distance) and "yes" (i.e., appropriate distance, Fig. 21) responses. The inflexion point is the distance at which participants respond half of the time (50%) "yes"; thus, it reflects the threshold of IPD or to what we referred to as "the minimum comfort distance". It can be retrieved from the parameters (α: the intercept and β: the slope) estimated from the logistic regression:

$$y = \frac{e^{(\alpha + \beta X)}}{1 + e^{(\alpha + \beta X)}} = \frac{1}{1 + e^{-(\alpha + \beta X)}} \qquad (8)$$

Where y is the probability of participants' "yes" response and X is the (crossing) distance. Indeed, when developing the equation with y = 0.5 (i.e., the inflection point), we can see that:

$$y = \frac{1}{1 + e^{-(\alpha + \beta X)}}$$

$$\frac{1}{y} - 1 = e^{(-\alpha - \beta X)}$$

$$\log\left(\frac{1}{y} - 1\right) = -\alpha - \beta X \qquad (9)$$

$$but\ since\ y = 0.5; \qquad -\beta X = \alpha$$

$$X = \frac{-\alpha}{\beta}$$

Therefore, X= $-\alpha/\beta$ represents the (crossing) distance when y = 0.5.

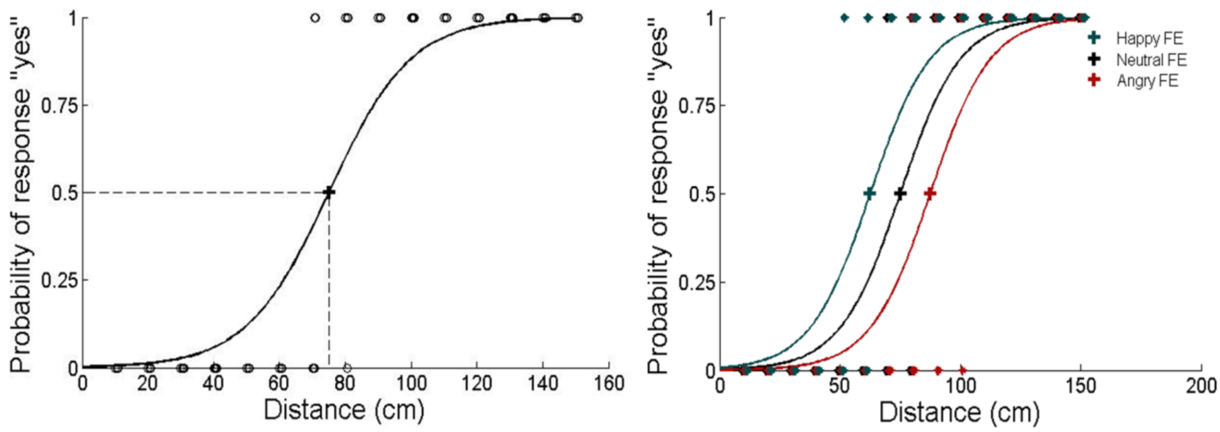

*Fig. 21. **Left panel**: Logistic regression from simulated (yes/no) responses (circles) at different distances varying from 10 to 150 cm by step of 10 cm. The sigmoid represents the fit of the logistic regression and the cross in its center represents the inflexion point at p^{-1} (0.5) = 75 cm. **Right panel**: simulated logistic regression for stimuli with happy (green), neutral (black) and angry (red) facial expression and their inflexion point (cross symbol).*

Despite its potential cost for participants because it requires a lot of trials (several repetitions per distance) and despite the extensive preliminary work its implementation requires (defining a distance range allowing the establishment of inflexion point for every condition, defining the appropriate step between each distance), this technic offers strong advantages. For instance, it provides a precise threshold and other precious indices related to the response certainty of participants such as the slope (β/4) and the dispersion of the responses (x when y =

0.84, Ernst & Banks, 2002). The constant stimuli method is also particularly useful when the hypotheses are easy to guess because participants cannot rely on the current trial to predict the next one, and they can hardly develop strategies to respond deliberately according to the experimental hypothesis without being noticed.

The purpose of our experimental setting, combining the different methods described just above, allowed us to test to some extent the link between PPS and IPD. More precisely during the first phase of Study 1 and 2, we recorded the EDA when the social stimuli were displayed within participant's reaching space as a function of their FE. In a second phase, we measured the preferred IPD for each FE. Then, we analyzed whether for each stimulus, preferred IPD could be linked to the electrodermal response and in particular with respects to neutral to threatening stimuli. It is well known that the physiological responses are very sensitive, thus the use of VR seemed particularly appropriate to maximize participants' immersion, favoring the observation of physiological responses relative to the experimental conditions.

Indeed, as we have seen in the introduction section, too short IPD (Kennedy et al., 2009) as well as threatening objects within the PPS (Rossetti et al., 2015) trigger a strong discomfort and the associated body responses. Thus, we first hypothesized that the level of discomfort felt when social stimuli displaying different FE were within the PPS could be reflected by the changes in EDA's intensity, expressed through the phasic driver index. We then hypothesized that this electrodermal response, as a proxy of threat perception, could predict the preferred IPD with the same social stimuli. The stronger the EDA to stimuli within the PPS, the higher threat perception, the larger the preferred IPD, and this should be related to the subjective evaluations of the social stimuli in terms of arousal and valence.

STUDY 1

Foreword

This study aimed at analyzing the effect of others' emotional state, conveyed by their FE, on the physiological response as well as on the interpersonal comfort distance. Furthermore, we wanted to investigate whether the increase in interpersonal comfort distance with negative and neutral social stimuli was linked to an increase in the physiological response. In this study, conducted in VR, participants first estimated whether PLD with the picture of an actor's face with an angry, neutral or happy FE on the head's position was reachable or not while their EDA was recorded. After that, participants had to judge whether the distance at which the same PLD crossed them was comfortable or not. Finally, they had to rate actors' faces in terms of valence and arousal. The methodological poster of a preliminary study is available in Appendix 3.

Physiological Response to Facial Expressions in Peripersonal Space Determines Interpersonal Distance in a Social Interaction Context

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Frontiers in psychology, 9, 657. https://doi.org/10.3389/fpsyg.2018.00657

Abstract

Accurate control of interpersonal distances in social contexts is an important determinant of effective social interactions. Although comfortable interpersonal distance seems to be dependent on social factors such as the gender, age and activity of the confederates, it also seems to be modulated by the way we represent our peripersonal-action space. To test this hypothesis, the present study investigated the relation between the emotional responses registered through electrodermal activity (EDA) triggered by human-like point-light displays (PLDs) carrying different facial expressions (neutral, angry, happy) when located in the participants peripersonal or extrapersonal space, and the comfort distance with the same PLDs when approaching and crossing the participants fronto-parallel axis on the right or left side. The results show an increase in the phasic EDA for PLDs with angry facial expressions located in the peripersonal space (reachability judgment task), in comparison to the same PLDs located in the extrapersonal space, which was not observed for PLDs with neutral or happy facial expressions. The results also show an increase in the comfort distance for PLDs approaching the participants with an angry facial expression (interpersonal comfort distance judgment task), in comparison to PLDs with happy and neutral ones, which was related to the increase in the physiological response. Overall, the findings indicate that comfort social space can be predicted from the emotional reaction triggered by a confederate when located within the observer's peripersonal space. This suggests that peripersonal-action space and interpersonal-social space are similarly sensitive to the emotional valence of the confederate, which could reflect a common adaptive mechanism in specifying theses spaces to subtend interactions with both the physical and social environment, but also to ensure body protection from potential threats.

Introduction

The space around the body is essential to interact physically and socially with the environment. Conceptualized as the peripersonal space, it is conceived as a multisensory interface between the body and the environment where objects can be reached and are naturally coded in terms of potential actions (Berti & Frassinetti, 2000; Cardellicchio, Sinigaglia, & Costantini, 2011; Coello & Delevoye-Turrell, 2007; Holmes & Spence, 2004; Iachini et al., 2014; Previc, 1998; Rizzolatti et al., 1997; Wamain et al., 2016). Dominant theories of spatial cognition consider that the peripersonal space is represented as an action space depending on the spatial properties of the environment and the dynamic characteristics of the body (Cléry et al., 2015; Coello & Iachini, 2015; di Pellegrino & Làdavas, 2015). As a consequence, modifying arm length in the body schema through tool-use (Bourgeois et al., 2014; Cardinali et al., 2012) or biasing the spatial outcome of manual reaching action (Bourgeois & Coello, 2012), also modifies the representation of the peripersonal space. Likewise, changing the value of objects in the environment through reward expectations also alters the representation of the peripersonal space (Coello et al., 2018). Due to its motor nature, increased activation in the sensorimotor brain areas has been reported when manipulable objects are presented in the peripersonal instead of extrapersonal space, even with tasks focusing on perceptual (Culham et al., 2008; Proverbio, 2012; Wamain et al., 2016), semantic (Wamain, Sahaï, Decroix, & Kalénine, 2018) or conceptual information about objects (Coello & Bonnotte, 2013; Coventry, Valdés, Castillo, & Guijarro-Fuentes, 2008).

More recently, peripersonal space has also been described as a safety space contributing to protect the body from external threat (Coello & Iachini, 2015; Iachini et al., 2014; Iachini, Ruotolo, Vinciguerra, & Ruggiero, 2017). In agreement with this, it has been reported that the presence of a threatening stimulus near the body alters the representation of the peripersonal space (Coello et al., 2012; Ferri et al., 2015; Graziano & Cooke, 2006; Valdés-Conroy et al., 2012). Likewise, an object of interest that is at hand could be ignored if it assumes a threat value due to the social situation. Consistently, in a monkey study, Fujii et al. (2007) showed that the parietal activity associated with the presence of a manipulable object within peripersonal space significantly reduced when another monkey, with a dominant status, was looking for the same object. This suggests that a manipulable object can be included or not in the peripersonal space depending on its value and the social context, which implies a specific modulation of the neuronal activity in the pre-frontal cortex in relation with the posterior parietal cortex (Fujii et al., 2009).

As a consequence, the peripersonal-safety space may influence the adjustment of interpersonal distances in social contexts (Hall, 1969; Hayduk, 1978; Knapp, Hall, & Horgan, 2013; Teneggi et al., 2013), suggesting that social and action spaces share common mechanisms (Iachini et al., 2014; Ruggiero et al., 2017). As evidence, Quesque et al. (2017) revealed an increase in the minimum interpersonal comfort distance after using a long tool, a typical enlargement effect known for peripersonal space (Bourgeois et al., 2014). This indicates that the representation of the peripersonal space constrains the spatial dimension of social interactions (but see Patané et al., 2016). Interpersonal distances can thus be viewed as the physical space between people where social interactions occur on the basis of their emotional and motivational relevance (Lloyd, 2009), but in relation with the representation of self and others' peripersonal space (Coello & Iachini, 2015). However, interpersonal distances may diverge from peripersonal space depending on the degree of affiliation with the interlocutor, defined by different variables such as gender, ethnicity, age, and also previous social experience (Iachini et al., 2016; Leibman, 1970; Tajfel et al., 1971). For instance, Iachini et al. (2016) showed that participants select larger comfort distance than reachability distance, in particular female participants when perceiving an approaching male confederate.

Identifying others' emotional state is an essential aspect of interpersonal social interactions, for which facial expressions may play a crucial role (Buck, Savin, Miller, & Caul, 1972; Darwin, 1872; Ekman & Friesen, 1971). Indeed, positive facial expressions generally foster approaching behavior whereas negative ones induce avoidance behavior, which means that the size of interpersonal distances perceived as comfortable may depend on the emotional context (Lockard et al., 1977; Ruggiero et al., 2017). In agreement with a link between peripersonal-action and interpersonal-social spaces, invasion of others' peripersonal space is usually experienced negatively and can cause intense discomfort and anxiety (Hayduk, 1978; Horowitz et al., 1964; Lloyd, 2009). Furthermore, psychological disorders such as social anxiety (Brady & Walker, 1978; Dosey & Meisels, 1969), claustrophobia (Lourenco, Longo, & Pathman, 2011), borderline personality disorder (Schienle et al., 2015), autistic spectrum disorders (Candini et al., 2017; Gessaroli, Santelli, di Pellegrino, & Frassinetti, 2013; Perry et al., 2015), or anorexia (Nandrino et al., 2017) are characterized by a prevalence of enlarged interpersonal distances for comfortable social interactions. In an fMRI study, Kennedy et al. (2009) reported a bilateral activation of the amygdala, a subcortical brain structure known to play a crucial role in emotion regulation, when the experimenter remained in the participants' peripersonal space during the scan acquisition. Increase in cortisol level and electrodermal activity (EDA) has also been reported in the context of uncomfortable social distances (Evans & Wener, 2007; McBride et al., 1965). Complementary evidence linking emotional, social, and spatial processes came from the observation that surgical resection of amygdala associated with temporal tumor surgery produced a severe deficit in the adjustment of interpersonal distances (Kennedy et al., 2009).

Stimuli valence and action system appear thus to contribute to the representation of both the peripersonal-action space and the interpersonal-comfort distance. However, little is known about the link between the body response to the presence of a confederate in the peripersonal space and the interpersonal comfort distance when socially interacting with the confederate.

The previous study by Ruggiero et al. (2017) has shown that peripersonal-action space and interpersonal-social space are both sensitive to the emotional valence of a virtual confederate approaching with different facial expressions. Depending on their valence, facial expressions may carry different emotional states and trigger different physiological responses in the observer, which can be detected in the sympathetic nervous system activation associated with the level of physiological arousal (Boucsein, 2012; Lang, Greenwald, Bradley, & Hamm, 1993). Accordingly, physiological responses triggered by a confederate's facial expression could be modulated by the peripersonal or extrapersonal position of the confederate. Furthermore, the physiological responses triggered by the confederate's facial expression in peripersonal space could be predictive of the interpersonal comfort distance in a social interaction task. In the present study, we tested these hypotheses by measuring the EDA triggered by a human-like virtual stimulus carrying different facial expressions, and by evaluating whether the interpersonal comfort distance during social interactions can be predicted on the basis of this physiological activity. A reachability judgment task toward the stimuli placed in either the peripersonal or extrapersonal space or at their boundary was used during the EDA recording. Then, a comfort distance judgment task was used to determine the minimum interpersonal comfort distance with stimuli carrying also different facial expressions. We expected that the presence in the peripersonal space of a confederate displaying a negative facial expression should produce a higher EDA in comparison to a confederate displaying a neutral facial expression, more particularly with male confederates who are usually maintained at a larger distance. Moreover, we expected the interpersonal comfort distances to increase in relation to the individual physiological response, in agreement with the protective role of the peripersonal space.

Materials and Methods

Participants

Thirty-seven healthy participants (17 women, M age = 21.7 years, SD age = 2.79) with normal or corrected-to-normal vision participated in the experiment. Participants gave written consent to take part in this study. The protocol received approval by the local Institutional Ethics Committee (Reference No. 2016-2-S41) and conformed to the principles of the Declaration of Helsinki (Medical Association World, 2013).

Materials and Stimuli

A schematic representation of the apparatus is presented in Fig. 22.A. Participants were standing at a distance of 1 m from a 4 m × 2 m screen, on which 3D visual stimuli were projected using rear projection from a stereoscopic video projector (Christie Mirage 4K25 DLP 3D projector). The visual stimuli consisted of human-like point like displays and were projected at 120 Hz with a 4 K spatial resolution (3840 × 2060 pixels). Active 3D eyewear (Christie) was used for producing 3D image perception. Stereoscopic images were displayed with off-axis projection by using non-symmetrical camera frustums in order to prevent vertical parallax while providing comfortable stereo pairs. The images were generated according to the participants' height and inter-pupillary distance. Thus, each eye received a different image for each stimulus alternately displayed at the rate of 8.33 ms. Normal fusion allowed perceiving the 3D moving visual stimuli and distances through relative size and binocular disparity.

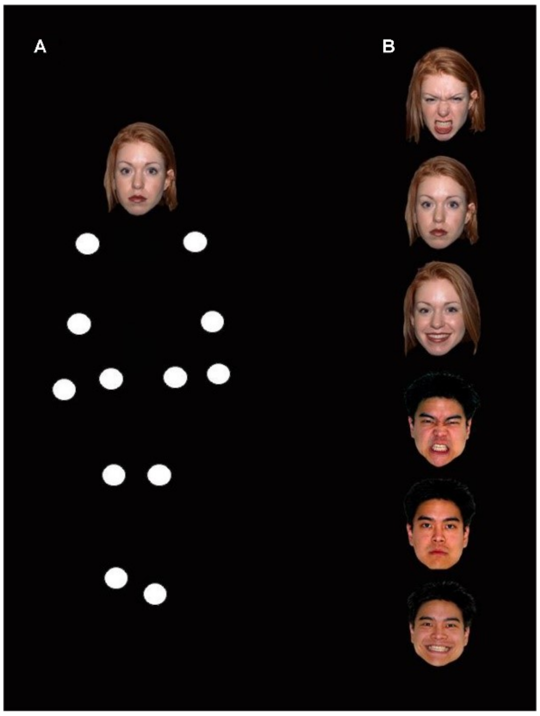

Fig. 22. (A) Illustration of the PLD used in the experiment (with a neutral facial expression). (B) Illustration of the facial expressions used in the experiment.

The stimuli consisted of human-like point-light displays (PLDs) representing adult males or females oscillating in place or walking toward the participants (Johansson, 1973). The PLDs were generated from adult models captured with a Vicon motion capture system, recording by means of six MX F20 near-infrared cameras (frequency 240 Hz) the position of 39 infrared markers distributed on the body and limbs (see Mouta et al., 2012 for a detailed description). The positions of 13 white dots (54 cd/m2) on a black background (0.4 cd/m2) were calculated by interpolation from the location of the markers, and signalized the motion of head as well as the left and right ankles, knees, hips, wrists, elbows, and shoulders. Pictures of human faces with different expressions were selected from the NimStim battery (Tottenham et al., 2009) and were associated with the dot representing the head on the PLDs. Geometrical characteristics of the head-picture were computed online to match the distance and size of the PLDs. 72 facial expressions were selected from the NimStim set of facial expressions: 12 female and 12 male faces each associated with a happy, angry, and neutral expression (see Fig. 22B). For each participant, a set 24 facial expressions was pseudo-randomly selected, including 12 female and 12 male faces each being associated with one single emotion resulting in 8 happy, angry, and neutral expressions. This selection process was used in order to avoid any specific effect of a particular expression associated to a particular face.

The stimuli were used in two tasks: a reachability judgment task and an interpersonal comfort distance task. In the reachability judgment task, the 24 PLDs with facial expressions were presented in both the participants' peripersonal space (at 65 cm) and extrapersonal space (at 250 cm, see Fig. 23.A). To allow their perception in 3D, they were oscillating in place without moving their feet. The oscillation activity consisted in a rotation of the whole body around the vertical axis with an angular rotation of about 20 to 30° at a frequency of 0.5 Hz. Another set of 10 PLDs with neutral facial expressions was presented during the reachability judgment task at the boundary of peripersonal space. This boundary was established from a pilot study (N = 20) consisting in indicating by pressing on a keyboard key when an approaching PLD (two males, two females, presented twice each) with different facial expressions (angry, neutral, happy) was at a reachable distance (mean: 150 cm, SD: 49 cm). In the experiment, the stimuli used were different than the one used in the pilot study and PLDs presented at the boundary of the peripersonal space were essentially used for the purpose of the reachability judgment task.

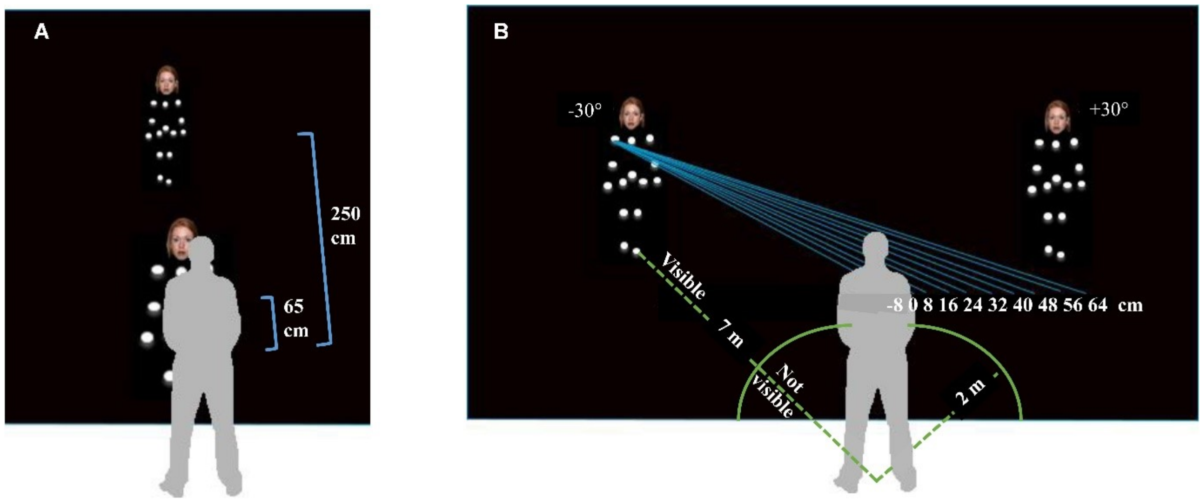

Fig. 23. (A) Location of the PLD (with a neutral facial expression) when presented in the participants' peripersonal space (at 65 cm) or extrapersonal space (at 250 cm). PLD located at the boundary of peripersonal space (at 150 cm) is not represented. (B) Schematic representation of the within-subject experimental conditions (not scaled for distance). The PLD started from two different locations (7 m, ±30°), crossed the participants' mid-sagittal axis, and disappeared at 2 m before virtually passing his/her fronto-parallel plane with an inter-shoulders distance of –8 to 64 cm on the right or left side.

In the interpersonal comfort distance judgment task (Fig. 23B), the same set of 24 PLDs with facial expressions were moving toward the participants and the displacement of the PLDs was perceived through the stereoscopic perception of the 13 white dots moving on the black background. In each trial, the PLDs appeared at a distance of 7 m from the participants, walking toward them at a constant speed of 1.2 m/s (simulated looming velocity was constant) and disappeared after having covered a distance of 5 m (thus, at a distance of 2 m from the participants). The PLDs could start walking from a side position located ±30° according to the participants straight ahead (minus sign for left locations). For each starting location, the PLDs could pass the participants' fronto-parallel plane either on their left or right side. For each side, 10 distances could separate the participants' and the PLDs' shoulders at the crossing location, from -8 up to 64 cm by step of 8 cm (negative signs representing collision with the body, see Fig. 23.B). The 0 cm condition was defined according to individual distance between the participants' mid-sagittal plane and shoulders. Since the PLDs disappeared at 2 m from the participant, the latter had to represent the end of the trajectory mentally until they represent the PLDs passing their fronto-parallel plane.

In the reachability judgment task, physiological responses were registered from EDA through a physiological amplifier BIOPAC MP36 (BIOPAC Systems, Inc., Goleta, CA, United States). Two Ag-AgCl electrodes filled with GEL101 electrolytic mixture were tied on the distal phalanges of the index and major fingers of the non-dominant hand of participants. The temperature of the room during the experiment was maintained at 21°C for all participants and the signal was recorded at a sample rate of 1000 Hz.

Procedure

Before starting the experiment, the participants were requested to fill a self-administered battery of questionnaires in order to control for exclusion criteria (no recent drug and alcohol consumption or excessive stimulating beverage, no previous history of neurological or psychiatric disorders). They also completed the State-Trait Anxiety Inventory STAI-YB (Spielberger 1983; French version by Bruchon-Schweitzer & Paulhan, 1993) and none of them highlighted depressive symptom (average score for anxiety-state: 31 and anxiety-trait: 41). Then, the experimenter placed the electrodes on the participant’s non-dominant hand and provided instructions concerning the experiment. The participants were placed in front of the vertical screen as described earlier and watched few examples of the human-like PLDs walking toward them from a straight-forward location (0°), and disappearing when reaching the distance of 20 cm from the participants. This practice session was performed in order to familiarize the participants with the virtual environment, the stereoscopic display and the PLDs. It was also performed to assess the correct 3D perception of the stimuli. Then, the participants started with the reachability judgment task and then performed the interpersonal comfort task.

Reachability Judgment Task

The reachability judgment task started with a 2 min baseline recording of the EDA while the participants were still staring at a black screen. Then, the reachability judgment task started and the 24 PLDs with different facial expressions were randomly presented in the peripersonal and extrapersonal space (thus 48 stimuli), intertwined with the 10 PLDs with neutral facial expressions presented at the boundary of peripersonal space. Thus, a total of 58 stimuli were randomly presented, articulated in two blocks of trials separated by a rest period. Because we used human-like PLDs, the stimuli were animated with an oscillatory movement so that they were perceptible with a 3D structure. Participants were requested to keep a stable posture and to estimate if the presented PLD was reachable with their dominant hand or not, but without performing the related arm movement. The PLDs were presented for a duration of 6 to 7.5 s (randomly selected), then a question mark appeared on the screen informing the participants that they had to provide their response. Reachable-unreachable responses (i.e., yes–no dichotomous responses) were provided with the index and major fingers of the dominant hand (counterbalanced across participants) using a computer keypad placed on a table located on the participants' side. A black screen appeared then for a duration of 4 to 5.5 s following the participant's response.

Interpersonal Comfort Distance Judgment Task

Participants had to judge whether the distance at which the PLDs crossed their fronto-parallel plane was comfortable or not (yes–no responses) by pressing one of two keys on the computer keypad with the index and major fingers of their dominant hand (counterbalanced across participants). The PLDs started walking 7 m from the participants, either at +30° or at -30° (for the left side) of eccentricity according to the participants' straight-ahead. For each starting location, the PLD crossed the participants' fronto-parallel plane with one of the 10 possible inter-shoulders distance (-8, 0, 8, 16, 24, 32, 40, 48, 56, 64 cm), randomly selected, and disappeared when reaching the distance of 2 m from the participants. The participants provided comfortability judgment after the PLD disappeared and when it had virtually reached the level of their (right or left) shoulder. Thus, 480 trials were performed, divided in three blocks of 160 trials with resting period between the blocks.

Post-experiment Stimuli Evaluation

Following the experiment, the participants were involved in a post-experiment debriefing and had to evaluate the different facial expressions in terms of emotion (arousal and valence) using the self-assessment manikin (SAM, M. M. Bradley & Lang, 1994). The evaluation was presented on a 30″ computer screen using Limesurvey's software. Overall, the experiment lasted around 2 h.

Data Analysis

Participant's responses and EDA were analyzed using MATLAB R2015b software (MathWorks, Inc., Natick, MA, United States) and statistical analysis was performed using R (version 3.4.1) and R Studio softwares (version 1.0.143). In the reachability judgment task, the dichotomic (yes–no) responses were recorded by the computer and the frequency of reachable responses was analyzed through a Space (peripersonal, extrapersonal) × Facial expression (angry, neutral, happy) ANOVA with repeated measures on both factors. The EDA was processed only for the PLDs presented in the peripersonal and extrapersonal spaces. Using the LEDALAB toolbox of MATLAB (Benedek & Kaernbach, 2010b), the physiological signal was down-sampled at 20 Hz and smoothed using the gauss-method with a 32 samples window. We first decomposed the physiological signal into tonic and phasic components using continuous decomposition analysis, then we analyzed the average of the phasic activity over each epoch

(CDA.SCR). The time window of interest was 0.5 to 6 s after stimulus onset. Linear mixed-effect model was used to analyze the phasic activity (μS) as a function of Facial expressions (angry, happy, neutral), Space (peripersonal, extrapersonal), PLD Gender (male, female) and Participant Gender (male, female). This data analysis takes into account interpersonal variability as random variables (lme4 1.1-13 package, Bates, Maechler, Bolker, & Walker, 2015). According to the full model:

$$Phasic\ Activity \sim (Facial\ expression\ *\ Space\ +\ PLD\ gender\ +\ Participant\ gender\ +\ (1\ |\ Participant)) \tag{10}$$

Reduced models (i.e., when removing fixed effects of interest) were compared using Likelihood Ratio test distributed like χ2 with degrees of freedom corresponding to the parameters estimate of each model. When significant, parameters of the models were associated with the corresponding t-value; p-values were obtained using normal approximation of the corresponding t-values. We also tested the phasic activity as a function of PLDs arousal and valence evaluation (SAM questionnaire). According to the models used:

$$Phasic\ Activity \sim (Arousal\ *\ Space\ +\ (1\ |\ Participant)) \tag{11}$$

$$Phasic\ Activity \sim (Valence\ *\ Space\ +\ (1\ |\ Participant)) \tag{12}$$

Concerning the comfort judgment task, the participants' responses were pooled for PLDs starting from the left and the right position (see Quesque et al., 2017, for details). Perceived minimum interpersonal comfort distance was determined using a maximum likelihood fit based on the second-order derivatives (quasi-Newton method) to obtain the logit regression model that best fitted the comfortable/uncomfortable responses (see Bourgeois & Coello, 2012, for details). We used the equation:

$$y = e^{(\alpha+\beta X)}/(1 + e^{(\alpha+\beta X)}) \tag{13}$$

in which y is the participants' (yes, no) response, X is the crossing distance, and (-α/β) is the critical value of X corresponding to the transition between comfortable and uncomfortable stimuli, thus expressing the perceived minimum comfortable distance. Statistical analyses were carried out using linear mixed-effects model to analyze the variation of minimum comfortable distance (cm) as a function of the condition. According to the full model:

$$Comfort\ Distance \sim (Facial\ expression\ +\ PLD\ gender\ +\ Participant\ gender\ +\ (1\ |\ Participant)) \quad (14)$$

We also tested the comfort distance as a function of PLDs arousal and valence evaluation (SAM questionnaire), according to the model:

$$Comfort\ Distance \sim (Arousal\ *\ Valence\ +\ (1\ |\ Participant)) \quad (15)$$

With respect to our hypotheses, the relation between the minimum comfort distance (interpersonal comfort distance judgment task) and the EDA (reachability judgment task) was analyzed for the PLDs with different facial expressions when located in the peripersonal space. Then, we used linear mixed-effect models in order to analyze the relation between the EDA phasic activity and the minimum comfort distance, according to the model:

$$Comfort\ Distance \sim (Phasic\ Activity\ +\ (1\ |\ Participant)) \quad (16)$$

Finally, PLDs arousal and valence evaluations depending on the facial expression (angry, neutral, happy) were analyzed from the SAM questionnaire responses using linear mixed-effects models, as follows:

$$Arousal \sim (Facial\ expression\ +\ (1\ |\ Participant)) \quad (17)$$

$$Valence \sim (Facial\ expression\ +\ (1\ |\ Participant)) \quad (18)$$

Results

PLDs Arousal and Valence Evaluations (SAM Questionnaire)

Concerning arousal evaluation, the value attributed to the PLDs was on average 1.57 (SD = 1.20) and depended on the facial expression [$\chi 2(2) = 390.31$, $p < 0.001$; angry PLDs: 2.23 (SD = 1.08); neutral PLDs: 0.47 (SD = 0.59); and happy PLDs: 2.01 (SD = 0.99)]. The evaluation of angry PLDs differed from the evaluation of happy PLDs (estimate = 1.80, SE = 0.08, t = 10.2, $p < 0.001$) and neutral PLDs (estimate = 1.94, SE = 0.07, t = 25.42, $p < 0.001$).

Concerning valence evaluation, the value attributed to the PLDs was on average 1.90 (SD = 1.40) and depended on the facial expression [$\chi 2(2) = 1195$, $p < 0.001$; with for angry PLDs: 0.23 (SD = 0.40); neutral PLDs: 1.92 (SD = 0.19); and happy PLDs: 3.53 (SD = 0.47)]. The evaluation of angry PLDs differed from the evaluation of happy PLDs (estimate = 3.31, SE = 0.04, t = 78.28, $p < 0.001$), but not neutral PLDs (t = 1.2, p = 0.22).

Reachability Judgment Task

Concerning the reachability estimates, PLDs presented in the peripersonal and extrapersonal space were respectively judged as reachable (94.4%) and unreachable (99.10%). Furthermore, reachability judgment for PLDs presented in the peripersonal and extrapersonal space was not influenced by the facial expression [$F(2,34) = 1.16$, p = 0.31], and there was no interaction between the two factors [$F(2,34) = 0.61$, p = 0.55]. PLDs at the boundary of peripersonal space with neutral facial expression were predominantly judged as unreachable (94.5%).

Concerning the EDA phasic activity, statistical analysis revealed a main effect of Space [$\chi 2(1) = 7.615$, p = 0.006] and an interaction between Facial expression and Space [$\chi 2(2) = 6.92$, p = 0.031, see Fig. 24]. PLDs in the peripersonal space led to an increase in the phasic activity in comparison to PLDs in extrapersonal space (estimate = 0.0006 μS, SE = 0.0002, t =

2.78, $p = 0.0054$) and the effect was higher for PLDs with angry facial expression than for PLDs with neutral facial expression (estimate = 0.002 µS, SE = 0.0006, $t = 2.95$, $p = 0.0032$). Finally, in the peripersonal space PLDs with angry facial expression led to a higher phasic activity in comparison to PLDs with neutral facial expression (estimate = 0.0012 µS, SE = 0.0004, $t = 3.11$, $p = 0.0018$). Statistical analysis also revealed an interaction between PLDs arousal evaluation and Space [$\chi2(1) = 7.57$, $p < 0.01$]. Stimuli evaluated as highly arousing resulted in a higher phasic activity in the peripersonal space (estimate = 0.0004 µS, SE = 0.0002, $t = 2.01$, $p = 0.045$). No other effect was significant.

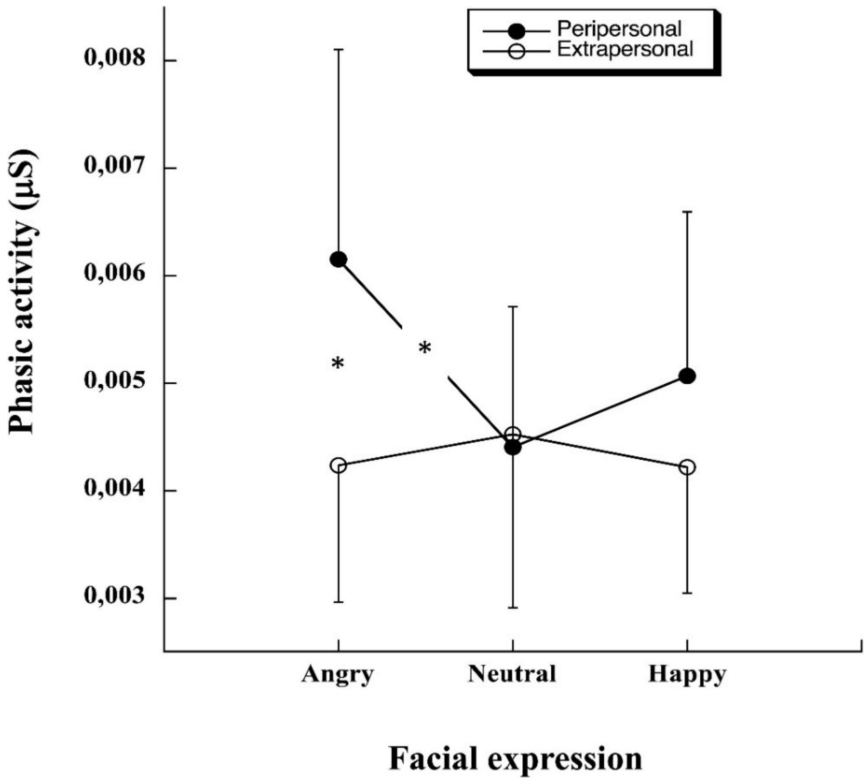

Fig. 24. Mean phasic activity (µS) and standard error as a function of the PLDs' facial expression (angry, neutral, happy) when located in either the participants' peripersonal or extrapersonal space.

Comfort Interpersonal Distance Judgment Task

Concerning the minimum interpersonal comfort distance (29.70 cm on average), statistical analysis revealed a main effect of Facial expression [$\chi2(2) = 87.15$, $p < 0.01$], with an increase in the minimum interpersonal comfort distance for angry facial expressions in comparison to neutral (estimate = 9.29 cm, SE = 1.10, t = 8.43, $p < 0.001$) and happy facial expressions (estimate = 10.17 cm, SE = 1.20, t = 8.43, $p < 0.01$, see Fig. 25). Statistical analysis also showed a main effect of PLDs Arousal evaluation [$\chi 2(1) = 73.71$, $p < 0.001$] and an interaction between Arousal and Valence [$\chi 2(1) = 5.74$, p = 0.0.02]. PLDs evaluated as highly arousing led to an increase in minimum interpersonal comfort distance (estimate = 3.54 cm, SE = 0.70, $p < 0.001$) and the effect was modulated by the valence rating (estimate = -0.76 cm, SE = 0.32, p = 0.02). No other significant effect was observed.

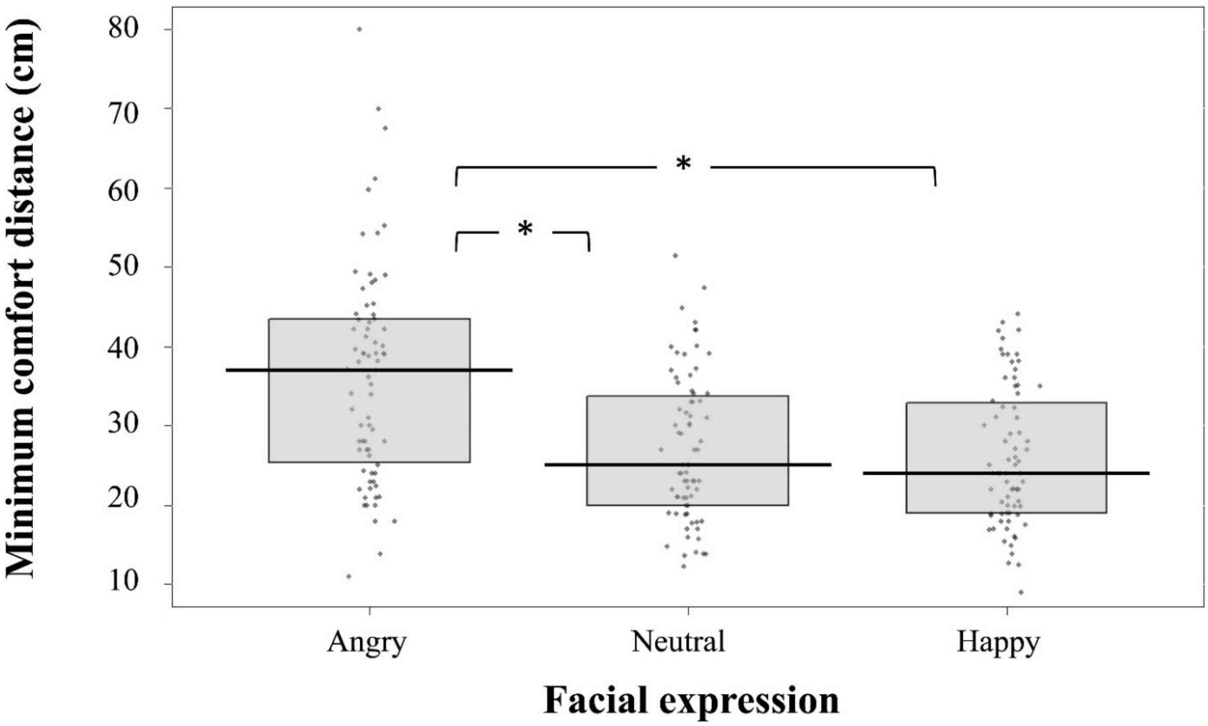

Fig. 25. Pirateplot (median and interquartile) representing the variation of minimum comfort distance (cm) as a function of the PLDs' facial expression (angry, neutral, happy).

Relation Between the EDA Triggered by PLDs in Peripersonal Space and the Interpersonal Comfort Distance

When considering facial expressions producing differences in EDA in the peripersonal space (angry and neutral facial expressions), we observed that the modulation of the phasic activity predicted the modulation of the minimum comfort distance [$\chi2(1) = 7.22$, $p < 0.01$], with a gain of 5.14 cm (estimate) per increase of 0.01 µS phasic activity ($SE = 1.88$, $t = 2.74$, $p < 0.01$, see Fig. 26).

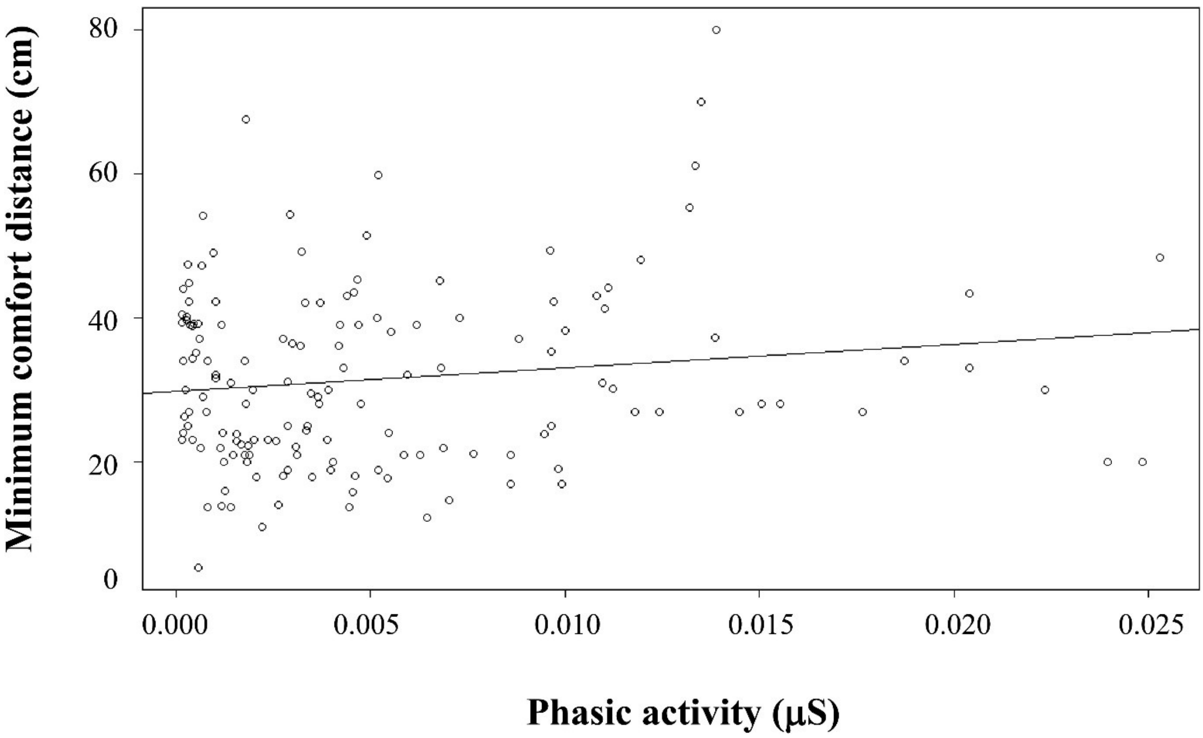

Fig. 26. Individual minimum comfort distance (cm) as a function of individual phasic activity (µS) for PLDs with angry and neutral facial expression presented in the peripersonal space. The linear relation indicates that 0.01 µS increase in phasic activity corresponds to an increase of 5.14 cm of minimum comfort distance.

Discussion

The aim of the present study was to examine how individual physiological response was modulated by human-like stimuli with different facial expressions in the participants' peripersonal space, and to demonstrate a relation between the individual physiological response and the interpersonal distances felt as comfortable when interacting with the same human-like stimuli. For this purpose, we used a reachability judgment task and an interpersonal comfort distance task, both performed with PLDs displaying happy, angry, or neutral faces.

With respect to the physiological responses in the reachability judgment task, we observed that angry, neutral and happy facial expressions triggered different EDAs in the participants. A significant increase in physiological response was registered for PLDs carrying an angry facial expression (arousal: 2.23; valence: 0.23) when located in the participants' peripersonal space in comparison to participant's extrapersonal space (gain of 45%) and for those same PLDs in comparison to PLDs carrying a neutral facial expression (arousal: 0.47; valence: 1.92) in participants' peripersonal space (gain of 40%). These results confirm the protective role of peripersonal space (Coello et al., 2012; Iachini et al., 2014, 2016; Kennedy et al., 2009; Ruggiero et al., 2017; Valdés-Conroy et al., 2012) and suggest that an invasion of the peripersonal space may trigger defensive behavior (Cléry et al., 2015; di Pellegrino & Làdavas, 2015; Graziano & Cooke, 2006). The need for maintaining a safety space around the body is particularly important in the presence of angry individuals who might be potentially harmful (Graziano & Cooke, 2006; Huffman, Horslen, Carpenter, & Adkin, 2009; Iachini, Pagliaro, et al., 2015; Kennedy et al., 2009; Seinfeld et al., 2018). Supporting this view, previous work on the role of the stimuli valence has revealed that the presence of a dangerous object near the body produces shrinkage of the peripersonal space (Coello et al., 2012). Furthermore, Ruggiero et al. (2017) reported an increase in the peripersonal space when an angry avatar was approaching a participant in a virtual reality display. Both results are compatible with a peripersonal space representing a multimodal interface to interact safely with the physical and social environment (Coello & Iachini, 2015; de Vignemont & Iannetti, 2015). In accordance with this view, unexpected invasion of peripersonal space may produce intense discomfort and anxiety (Hayduk, 1978; Horowitz et al., 1964; Lloyd, 2009). Furthermore, high trait anxiety is usually associated with an extended peripersonal space (Iachini, Ruggiero, et al., 2015). In the present study, the protective role of peripersonal space is also highlighted by the observation that the PLDs located in the participants' peripersonal space modulate the EDA, confirming the established link between threat and associated physiological response. In accordance with this, the more the participants rated stimuli as arousing, the more their physiological responses increased when the PLDs were in their peripersonal space (Bach, Friston, & Dolan, 2010; Sequeira, Hot, Silvert, & Delplanque, 2009). These results confirm thus the safety role of the peripersonal space and show how threatening stimuli have an impact on the physiological activity (Coello et al., 2012; Ferri et al., 2015; McBride et al., 1965; Rossetti et al., 2015; Ruggiero et al., 2017; Szpak et al., 2015).

As regards reachability judgments, the participants judged, as expected, almost all PLDs in peripersonal space as reachable (94.4%) and almost all PLDs in extrapersonal space as unreachable (99.10%). Concerning the PLDs located at the boundary of peripersonal space, the participants judged them as unreachable in 94.46% of the cases. This bias toward unreachability for stimuli located at the boundary of peripersonal space could be explained by the fact that the latter was determined in a pilot study using approaching stimuli. Previous studies have indeed shown that peripersonal space increased when a confederate approached a passive participant, in comparison to a situation where the participant was moving toward the confederate (Iachini et al., 2014; Ruggiero et al., 2017). The fact that the boundary of peripersonal space was specified in our study on the basis of approaching PLDs could explain the prevalence of unreachable responses when judging afterward the reachability of stationary PLDs.

With respect to the interpersonal comfort distance, the minimum distance was on average 30 cm (inter-shoulder distance), which is in agreement with previous studies (e.g., 32 cm in Quesque et al., 2017). We found that the minimum comfort distance increased with PLDs carrying angry facial expressions in comparison to PLDs with neutral ones (34%) and in comparison to PLDs with happy facial expressions (39%). The present data confirm the effect of valence of facial expressions on comfortable interpersonal distances (Lockard et al., 1977; Ruggiero et al., 2017). Facial expressions rated as negative (e.g., angry facial expressions) led to an increase in the comfortable interpersonal distance in comparison to those rated more positively (neutral and happy facial expressions). We also found that the more facial expressions were rated as arousing by individuals, the more the minimum comfort distance increased and that this relation was modulated by the valence evaluation of the same stimuli. The increase in minimum comfort distance in relation to the increase in arousal was indeed lower when the valence was rated positively. These findings corroborate the previous observation that spatial distance enlarges in the presence of angry faces compared to neutral and happy faces, with no difference between the last two (Ruggiero et al., 2017). However, the present study went further by demonstrating that this enlargement was also associated with the subjective evaluation of the faces (including both valence and arousal).

Surprisingly, neither the participants' nor the PLDs' gender was found to modulate the minimum comfort distance in the social interaction task, which contrasts to what was reported in previous research (e.g., Iachini et al., 2016; McBride et al., 1965). For instance, Iachini et al. (2016) described an increase in the minimum comfort distance from male virtual confederates in comparison to female ones. The main findings were that peripersonal space and interpersonal distances shrank with humans as compared to objects (Iachini et al., 2014), and both spaces were affected by age and gender, i.e., decreased with children and females as compared to adult males, thus reflecting, respectively, affiliative and attraction mechanisms (Argyle & Dean, 1965;

McBride et al., 1965; Uzzell & Horne, 2006). The different effect of gender on interpersonal social space observed in these studies and the present one could be due to the importance of facial expressions, which may have prevented or reduced the effect of gender (see also Ruggiero et al., 2017). Although facial expressions and gait were gendered, the emotions displayed might capture most of the attention available while putting aside less relevant features such as gender.

Another important point raised by the present study concerns the relation between the physiological response associated with PLDs in the participants' peripersonal space and the minimum comfort distance accepted with the same stimuli. When considering PLDs with angry and neutral facial expressions (i.e., the ones statistically different in the two tasks), we found a significant relation between the change of the EDA (reachability judgment task) and the change of the preferred social distance (comfort interpersonal distance judgment task), associated with the different valence of the facial expressions. We also observed that the more the physiological response increased in the presence of a negative facial expression, the more the interpersonal distance of comfort widened. Precisely, a gain of 0.01 µS for the phasic activity for stimuli presented in the peripersonal space corresponded to an increase in the comfort distance of 5.14 cm. Information regarding the emotional state of a confederate in a social context would trigger physiological automatic response likely to help adapting distance to the confederate in order to feel safe. It is worth noting that EDA was acquired during the reachability judgment task only and not also during the comfort interpersonal distance judgment task in order to avoid any habituation effect of the emotional stimuli on EDA, but which represents a limitation of the present study. Another extension of the present work would be to compare these data to the postural stability of participants while threatening stimuli are approaching them. This might indeed inform us about the implicit behavioral withdrawal strategy adopted along with the physiological responses. An additional interesting aspect would be to manipulate the characteristics of the PLDs in order to study whether other characteristics of the human-like stimuli (size, status, previous experience…) are taken into account to specify the spatial component of social interactions.

Taken together, these results confirm the protective role of peripersonal-action space and support its role in the adjustment of interpersonal comfort distances for appropriate social interactions (Coello & Iachini, 2015; Iachini et al., 2014; Quesque et al., 2017; Ruggiero et al., 2017). The increase in the physiological response to PLDs with angry faces may represent an automatic avoidance reaction to the violation of the near body space, as a consequence of arousal regulation and the necessity to ensure a stable self-protection (Dosey & Meisels, 1969; Hayduk, 1983; Siegman & Feldstein, 2014). The strong physiological response in the presence of angry faces is consistent with neurofunctional and behavioral studies showing that negative stimuli yield stronger body response than positive stimuli (Cacioppo, Priester, & Berntson, 1993; Cole et al., 2013; de Gelder et al., 1999; Öhman, 1987; Strack & Deutsch, 2004; van Dantzig, Pecher, & Zwaan, 2008; Vuilleumier & Pourtois, 2007). Thus, the proximity of a threatening confederate obviously leads to avoidance mechanisms in the form of an increase in the social distance, with the consequence that non-appropriate social distance leads to physiological warning signal inducing defense behavior (Evans & Wener, 2007; Kennedy et al., 2009; Lockard et al., 1977; Ruggiero et al., 2017). In contrast, positive elements such as happy facial expressions might foster social interactions (Cole et al., 2013; Lockard et al., 1977; Ruggiero et al., 2017).

Conclusion

The present study showed that both peripersonal-action space and interpersonal-social space are similarly sensitive to the emotional meaning of stimuli, which suggests that they may rely on common mechanisms in relation to the motor action system. It also brings new information regarding the emotional coding of threat in terms of distances and how safety can be quantified physiologically and spatially.

STUDY 2

Foreword

This second study aimed at analyzing whether the effects raised in Study 1 were maintained when presenting facial expressions at the perceptual threshold. Indeed, it is quite common to only surreptitiously glimpse others' FE. This study was therefore relatively ecological in this regard to everyday life situations. In Study 1, we observed an increase in EDA when characters with an angry FE were presented in the PPS when compared to the extrapersonal space or in comparison to characters with a neutral FE in the PPS. We also observed an increase in IPD for the characters with an angry FE in comparison to characters with neutral and happy FE. Finally, we pointed out that this increase in IPD was linearly related to the physiological changes triggered by the characters within the PPS when focusing on neutral to threatening (PLD with angry FE) stimuli.

In Study 2, participants first performed a task of FE categorization (angry, neutral, happy). The pictures were presented during 16 ms and their luminance varied in order to establish an individual threshold of perception. In the second task, participants estimated whether the crossing distance between themselves and the PLD was comfortable or not. The PLD were preceded by a new set of actor's faces with an angry, happy or neutral FE presented at the individual perceptual threshold. In the first session of this second task, participant's EDA was recorded at three crossing distances (collision between both shoulders, at the average IPD established during Study 1 and at a comfortable distance). In the second session, every distance was presented in order to establish IPD as a function of FE. In the last task, participants judged the actors' faces in terms of valence and arousal. The methodological poster of a preliminary study is available in Appendix 4.

The influence of facial expression at perceptual threshold on electrodermal activity and social comfort distance

Cartaud, A., Ott, L., Iachini, T., Honoré, J., & Coello, Y. (2020).
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Abstract

Interpersonal distance, an essential component of social interaction, is modulated by the emotion conveyed by others and associated physiological response. However, in modern societies with overcrowded and hyperstimulating environments, we can only surreptitiously glimpse the faces of others in order to quickly make behavioural adjustments. How this impacts social interactions is not yet well understood. In the present study, we investigated this issue by testing whether facial expressions that are difficult to identify modify the physiological response (Electrodermal Activity, EDA) and subsequent judgment of interpersonal comfort distance. We recorded participants' EDA while they provided comfort judgments to interpersonal distances with a Point-Light Walker (PLW). The PLW, with an emotionally neutral gait, moved towards and crossed participants at various distances after the latter were exposed to a negative (anger), positive (happiness) or neutral facial expression presented at the perceptual threshold. Bayesian analyses of the data revealed an increase vs decrease in interpersonal comfort distance with the PLW depending on the negative vs positive emotional valence of the facial expression. They also showed an increase in EDA when the approaching PLW violated interpersonal comfort distance after participants were exposed to an angry facial expression. These effects correlated with the subjective assessment of the arousal of facial expressions. Thus, previous exposure to barely visible facial expressions can alter the representation of social comfort space and the physiological response associated with a violation of interpersonal comfort distances, depending on the valence and arousal of the emotional social stimuli.

Keywords: Social interaction, interpersonal space, facial expression, electrodermal activity, physiological response, perceptual threshold, visual masking

Introduction

Among the numerous non-verbal signals in a social situation, facial expressions are considered as crucial indications for interpreting the current social context and identifying potential sources of hazards and threats. However, in our modern societies characterised by overcrowded and hyperstimulating environments, we can only surreptitiously glimpse the faces of others and quickly make behavioural adjustments almost without realizing it. How the emotional signals carried by others' faces, which can be difficult to identify because of their poor visibility (e.g., quickly glimpse, poor lightening, overcrowding…), transience and diversity, influence our social behaviour remains an open issue. A key component of social interactions is the adjustment of interpersonal distance both in animals (Hediger, 1968) and in humans (Hall, 1966; Hayduk, 1978). Selecting an appropriate interpersonal distance involves two constraints: the need to approach conspecifics to interact with them and the need to maintain a margin of safety with others to protect the body from external hazards (Dosey & Meisels, 1969; Hayduk, 1983; Siegman & Feldstein, 2014). As evidence for a protective spatial buffer around the body, a strong physiological response was reported when non-familiar conspecifics unexpectedly violated the margin of safety of others, producing in them an increase a) in electrodermal activity (McBride et al., 1965), b) in the activity of the neuro-emotional network including the amygdala (Kennedy et al., 2009), and c) in the level of stress-related hormones such as cortisol (Evans & Wener, 2007).

Previous studies suggested that interpersonal comfort distance is related to how one represents the space where we can act on reachable objects with the body (i.e., the peripersonal space, Quesque et al., 2017, but see Patané, Farnè, & Frassinetti, 2017). As evidence, Quesque and collaborators revealed that using a tool, which is known to modify arm's length in the body schema, resulting in an increase in the peripersonal space, also alters preferred interpersonal distances (Quesque et al., 2017). Moreover, the fronto-parietal structures supporting peripersonal space representation were found to contribute also to interpersonal distance adjustment (Vieira et al., 2019). Interpersonal comfort distance is also modulated by a number of variables, including cultural habits (Hall, 1966), ethnicity (Leibman, 1970), gender and age (Iachini et al., 2016), prior information about people's morals (Iachini, Pagliaro, et al., 2015) and psychopathological characteristics (Nandrino et al., 2017). Accordingly, individuals suffering from social anxiety (Dosey & Meisels, 1969), claustrophobia (Lourenco et al., 2011), borderline personality disorder (Schienle et al., 2015) or autistic spectrum disorder (Candini et al., 2017; Perry et al., 2015) usually prefer wider interpersonal distances, whereas those with high psychopathic traits usually prefer narrower interpersonal distances (Rimé et al., 1978; Vieira & Marsh, 2014; Welsch et al., 2018).

Non-verbal behaviour such as facial expressions also provides crucial clues in the adjustment of interpersonal distances (Cartaud, Ruggiero, Ott, Iachini, & Coello, 2018; Lockard et al., 1977; Ruggiero et al., 2017; Vieira et al., 2017). Previous studies suggested that facial expressions are processed quickly and automatically because they are an essential component of social interactions and are important for survival (Buck et al., 1972; Darwin, 1872; Ekman & Friesen, 1971; Schrammel, Pannasch, Graupner, Mojzisch, & Velichkovsky, 2009). Therefore, perceiving positive facial expression (i.e., happiness) usually leads to a reduction in interpersonal comfort distance (Lockard et al., 1977; Ruggiero et al., 2017), while perceiving negative facial expression (e.g., anger) usually leads to an increase in interpersonal comfort distance (Cartaud et al., 2018). Furthermore, the physiological response to the violation of interpersonal comfort distance depends on the valence of the emotion carried by the intruder's face. In particular, it was found that neural activity in the amygdala increases in the presence of an angry or fearful facial expression, but not in the presence of neutral or happy facial one (Whalen et al., 2001). Moreover, the neural response is positively correlated with the preferred distances selected with these facial expressions (Vieira et al., 2017). EDA used as a proxy of physiological response to emotional stimuli is also modulated by the valence and arousal of facial expressions (Buck et al., 1972; Lang et al., 1993) and more significantly when the emotional stimuli are in the peripersonal space (Cartaud et al., 2018).

Although it is widely accepted that facial expressions modulate both the electrodermal activity and interpersonal distance, it is not yet known how barely visible facial expressions modulate physiological response and alter behavioural adjustment to subsequent interactions with neutral social stimuli, even though this situation occurs every day. To address this issue, we conducted an experiment in which the difficulty to identify a facial expression was controlled by presenting the visual stimuli at perceptual threshold using forward and backward visual masks (Breitmeyer, 2007; Deplancke, Madelain, & Coello, 2016; Lamme, Supèr, Landman, Roelfsema, & Spekreijse, 2000; Macknik & Martinez-Conde, 2009). After being exposed to a barely visible facial expression (anger, happiness, neutral), participants provided a comfort judgment of interpersonal distance with an approaching human-like point-light walker (PLW with a neutral gait) crossing them at different distances, and EDA was recorded. We expected an increase in EDA when participants were previously exposed to an angry facial expression presented at perceptual threshold, especially when the PLW violated the participants' interpersonal comfort distance. Moreover, we expected interpersonal comfort distance to increase or decrease when the approaching PLW was preceded by an angry or happy facial expression, respectively, compared to a neutral one. Finally, we expected the magnitude of these effects to be related to the level of subjective arousal associated with the facial expressions.

Method

<u>*Participants*</u>

Forty-five healthy right-handed participants with normal or corrected-to-normal vision participated in the experiment. Due to the poor quality of the electrodermal activity recording for six of them, only 39 (27 women, M_{age} = 19.69 years, SD_{age} = 1.10) were included in the data analysis. They all gave their written informed consent, and the protocol received approval by the local Institutional Ethics Committee (Reference No. 2018-279-S61) and conformed to the principles of the Declaration of Helsinki (World Medical Association, 2013).

Apparatus and stimuli

Participants stood 1 m from a 4 m x 2 m screen on which 3D visual stimuli were rear-projected with a spatial resolution of 4 K (3840 x 2060 px), using a stereoscopic video projector and Christie 3D active glasses (see Cartaud et al., 2018 for a detailed description). The stimuli consisted of 16 male and female faces selected from the NimStim set of facial expressions (Tottenham et al., 2009). Each face was associated with an angry, happy, or neutral facial expression (faces with an angry or happy expression had an open mouth but not neutral faces). The size of the face corresponded to that of an actual face presented 0.9 m from the participant. To display facial expressions at the perceptual threshold, the faces were displayed for 16.67 ms and were preceded and followed by a visual mask. The forward and backward visual masks[1] corresponded to a distorted version of the face displayed and were presented with a duration randomly selected between 0.8 s to 1 s (see below for the procedure). They were computed online and consisted in randomly shifting vertically and horizontally each pixel composing the face, according to an [-100 px, +100 px] interval centred on the pixel's position. Then a random angle was applied (noise.spread plugin developed by Micheal Mure and implemented in Gimp

[1] According to neurophysiological models of visual perception, the conscious processing of a visual stimulus depends on two neural activities: a first stimulus-dependent activity observed in the form of a transient feedforward sweep of activation (transient channel) and a second activity mediated via sustained re-entrant activations from higher cortical areas (sustained channel: Breitmeyer, 2007; Macknik & Martinez-Conde, 2007, 2009; Supèr & Lamme, 2007). Within this framework, backward visual masking has been shown to selectively suppress the second perceptual-dependent component of the neural response, whereas forward visual masking is thought to suppress the first stimulus-dependent component of the neural response along with partial suppression of its later component (Breitmeyer, 2007; Deplancke et al., 2016; Lamme et al., 2000; Macknik & Livingstone, 1998; Macknik & Martinez-Conde, 2009).

(https://github.com/MichaelMure/gimp-plugins/blob/master/common/noise-spread.c). This masking procedure allowed the colour and light flow of the visual stimuli to be maintained while altering the visual features and visibility of the faces.

The facial expressions and their masks could be followed by the PLW (see procedure section) that consisted of 13 white dots presented on a black background which provided information about the movement of the head, left and right ankles, knees, hips, wrists, elbows, and shoulders (see Mouta, Santos, & Lopez-Moliner, 2012), without providing any about the body itself. When displayed, the PLW appeared congruently with the location of the face, the starting position of the PLW was ±30 deg in relation to the perpendicular gaze of the participants (minus sign for left locations). It remained still for 0.5 s, then walked towards the participants at a constant speed of 1.2 m/s (simulated looming velocity was constant, Mouta et al., 2012), and finally disappeared when reaching a distance of 1.5 m from them. The PLW approached the participants with a gender-dependent (depending on the face) but emotionally neutral gait kinematics. Its trajectory crossed the participants' fronto-parallel plane either on their left or right side. The inter-shoulder distance at the crossing point (i.e., distance between the participants' shoulder and the PLW's shoulder) could vary between -8 and 72 cm (by 8 cm increments, negative sign representing collision with the participants). The 0 cm condition was specified for each participant and was calculated according to the distance separating the mid-sagittal body axis from the participants' shoulder). Participants physiological responses were registered by EDA through a BIOPAC MP36 physiological amplifier (BIOPAC Systems, Inc., Goleta, CA, United States). Two Ag-AgCl electrodes filled with GEL101 electrolytic mixture were tied on the distal phalanges of the index and major fingers of the non-dominant hand (Fowles et al., 1981). The room temperature during the experiment was maintained at 21°C for all participants, and the signal was recorded at a sample rate of 1000 Hz.

Procedure and measures

Before starting the experiment, participants were requested to complete a self-administered battery of questionnaires on LimeSurvey (version 2.63.1) in order to control for exclusion criteria (no drug and alcohol consumption or excessive stimulating beverage within the last 24 hours, no previous history of neurological or psychiatric disorders). The battery also included the Edinburgh Test and the State-Trait Anxiety Inventory STAI-YB (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983; French version by Bruchon-Schweitzer & Paulhan, 1993) to check for laterality (M = 0.78, SD = 0.32, Oldfield, 1971) and atypical anxious symptoms (which was the case for none of the participants with an average anxiety-state score: 29.31 SD = 4.95 and anxiety trait: 43.36 SD = 8.16). Then, participants were placed in front of the vertical screen as described earlier and were given instructions. They started with the perceptual threshold determination task, followed by the comfort judgment of interpersonal distance task, and ended with the subjective assessment of arousal of facial expressions. The two sessions of comfort judgment of interpersonal distance were set up in order to analyse both the physiological (EDA, session 1) and behavioural (interpersonal comfort distance, session 2) responses, while limiting the habituation effect associated with repeated stimuli on the physiological responses. Accordingly, in session 1 the PLW crossed the participants' fronto-parallel plane at only three inter-shoulder distances (-8, 32, 72 cm) whereas in session 2, the participant encountered every condition (-8 to 72 cm by step of 8 cm) so that behavioural responses could be accurately analysed. All tasks were programmed using Psychtoolbox-3 (Kleiner et al., 2007).

Perceptual threshold determination

To determine psychophysically the perceptual threshold of facial expressions, participants had to identify the facial expressions in a set of four faces (two males and two females with three facial expressions). Each facial expression (angry, happy and neutral) was associated with a specific response key (1, 2 and 3 on the keypad) and a familiarization phase was included. Each face was displayed for 16.67 ms between a forward and a backward visual mask but the mean luminance of the face (and that of the masks) was modified in each trial by adjusting the values of the channels in the HSV colour space (Hue, Saturation, Value) to a given mean between 0 and 0.2 by step of 0.02 (0 and 1 corresponding respectively to no luminance and full luminance, see Fig. 27).

Fig. 27. Illustration of facial expressions and masks used in experiment with different levels of luminance (top face and masks: maximum luminance, bottom face and masks: medium luminance).

Thus, two faces per gender were presented randomly with three facial expressions across 11 luminance ratios resulting in a total of 132 trials (method of constant stimuli). We thus determined the averaged perceptual threshold of the facial expressions. Despite the happiness and anger superiority effect in visual perception (Brosch et al., 2008; Hansen & Hansen, 1988), we decided to use the same perceptual threshold for every facial expression, including the neutral stimuli. Indeed, as the same individual luminance was used for the facial expression and for the forward and backward masks, using a different luminance threshold as a function of the facial expression would have provided anticipatory information about the forthcoming facial expression as soon as the forward mask appeared. The threshold (66.67% of the correct responses, each stimulus being associated with three possible responses, chance level corresponded to 1/3 of the correct responses) was determined using a maximum likelihood fit procedure based on a second-order derivative optimization method to obtain the logit regression model that best fitted the participants' correct vs wrong identification of the facial expressions using the equation:

$$y = \frac{1}{3} + (1 - \frac{1}{3}) * \frac{e^{(\alpha + \beta X)}}{1 + e^{(\alpha + \beta X)}} \tag{19}$$

where y is the participants' probability of giving a correct answer for each facial expression (from 1/3 to 1) at the luminance ratio X, and (-α/β) is the critical value of X corresponding to the transition between correct/non-correct responses expressing thus the perceptual threshold of facial expressions. For each participant, temporal and luminance parameters associated with individual perceptual thresholds were registered and then used in the subsequent comfort judgment of interpersonal distance task (session 1 and 2) for presenting facial expressions at the perceptual threshold. The mean luminance threshold was 0.12 with a 95% confidence interval between 0.11 and 0.13.

Comfort judgment of interpersonal distance

Session 1: Physiological responses

After having determined the individual perceptual threshold, the experimenter equipped participants with electrodes placed on the index and major fingers of the non-dominant hand and provided instructions before starting the comfort judgment of interpersonal distance task. Following a training session including six trials, the task began with a 30 s recording of the EDA while the participants were still and staring at a black screen (signal stabilization period after participants moved from sitting to standing position). Then, they were requested to judge whether the distance at which the approaching PLW crossed their fronto-parallel plane was comfortable or not (2-AFC paradigm). At the beginning of each trial, a facial expression at the individual perceptual threshold was displayed, then the PLW approached and disappeared when reaching the distance of 1.5 m from the participants. Once the PLW had disappeared, participants provided their comfort judgment with the index and major fingers of the dominant hand (counterbalanced across participants) by pressing the ENTER or PLUS keys of the keypad positioned on a table near their right hand. Participants thus had to represent the end of the trajectory mentally until they represented the PLW crossing their fronto-parallel plane. Irrespective of its starting location (±30°), the PLW walked 4.5 m and crossed the participants' fronto-parallel plane according to three possible inter-shoulder distances (-8, 32 or 72 cm) randomly selected. A new set of 12 faces (6 males and 6 females, not seen before) was used and each face was associated with only one facial expression (angry, happy or neutral), resulting thus in two faces per gender per facial expression. To limit the habituation effect leading to a decrease in the physiological response, each face was presented only once per crossing distance on either the left or right side (randomly selected). A black screen then appeared for a random duration of 4 to 5.5 s following the participants' response. Participants performed 36 trials in a single block (2 genders x 3 facial expressions x 3 crossing distances x 2 starting locations). The schematic representation of a typical trial is displayed in Fig. 28.

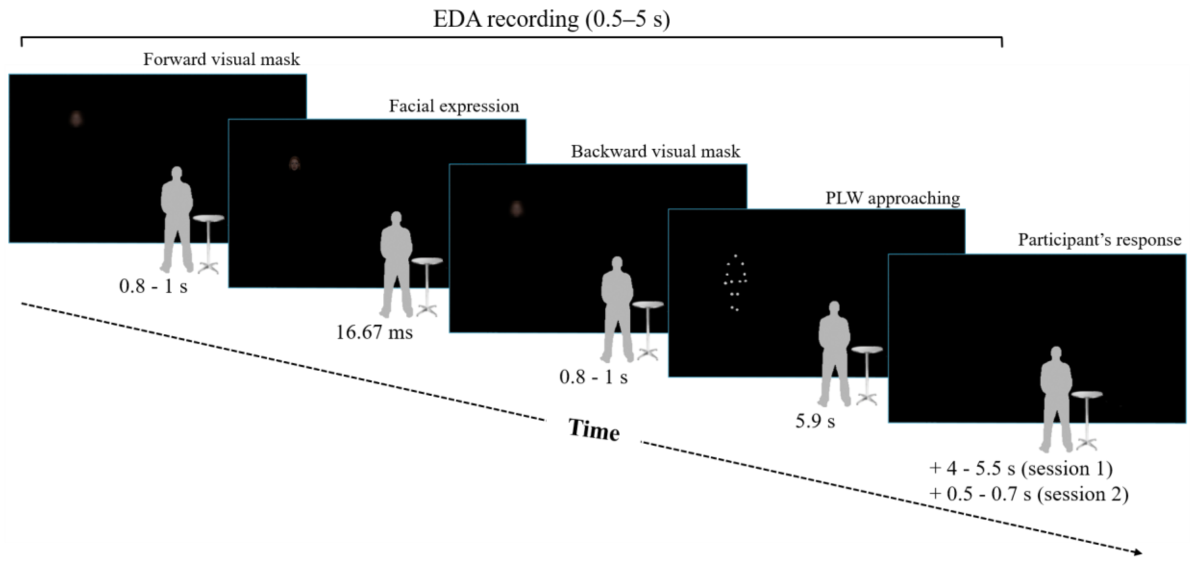

Fig. 28. Sequence of events in trial during comfort judgement of interpersonal distance task. Participants had to judge whether the PLW crossed their fronto-parallel plane at a comfortable inter-shoulder distance or not. Keypad placed on table near right hand of participants.

Session 2: Behavioural responses

This task was similar to the previous one, i.e., participants had to judge whether the distance at which the PLW crossed their fronto-parallel plane was comfortable or not. However, electrodermal activity was not recorded, and the latency separating the participants' response from the following trial was randomly selected between 0.5 and 0.7 s. Furthermore, for each starting location the PLW crossed the participants' fronto-parallel plane at one of the 11 possible inter-shoulder distances on the contralateral side (from -8 to 72 cm by step of 8 cm). A total of 264 trials was performed (2 faces x 2 genders x 3 facial expressions x 11 crossing distances x 2 starting locations) divided in three blocks with a resting period before each new block. This session allowed a precise evaluation of the boundary of interpersonal comfort distance of each participant.

Post experimental stimuli assessment

At the end of the experiment, participants were requested to provide a subjective evaluation of the emotional intensity (arousal) of the facial expressions (SEI, 0: low intensity; 10: high intensity). The facial expressions were presented at the perceptual threshold in the centre of the screen 0.9 m from the participants. When the face disappeared, a horizontal line with a cursor in the middle was displayed indicating "low intensity" on the left side and "high intensity" on the right side. The horizontal line remained on the screen until the response was provided by the participants with the computer mouse. This evaluation was used only as a control variable for the analysis of the physiological and behavioural responses. The mean SEI and its 95% confidence interval were 5.05 [4.63, 5.48] for angry facial expressions, 5.43 [5.01, 5.95] for happy ones and 2.42 [2.05, 2.78] for neutral facial expressions. Overall, the experiment lasted about two hours, including a debriefing of the experiment.

Data recording and analysis

Participants' EDA was analysed using the LEDALAB toolbox (version 3.4.9, Benedek & Kaernbach, 2010). The physiological signal was first down-sampled at 20 Hz, then smoothed using a 50-sample gaussian window filter corresponding to a cut-off frequency of 0.42 Hz. We first decomposed the physiological signal into tonic and phasic components using continuous decomposition analysis. Then, we analysed the average of the phasic information in the signal (phasic driver, a proxy of sudomotor nerve response) over each epoch (CDA.SCR). The time window of interest was 0.5 to 5 s following stimulus onset. Five trials associated with unexpected actions from the participants were removed from the analysis (e.g., coughing, 0.36% of the trials). Comfort judgments were analysed from the (comfortable/not comfortable) responses provided by the participants depending on the inter-shoulder distance and the facial expression. Participants' responses were pooled for the PLW starting from the right and left side (see Quesque et al., 2017 for details). The boundary of interpersonal comfort distance was determined from the participants' responses at each distance using the equation:

$$y = \frac{e^{(\alpha + \beta X)}}{1 + e^{(\alpha + \beta X)}} \tag{20}$$

in which y is the participants' (comfortable/not comfortable) response, X is the crossing distance, and (-α/β) is the critical value of X corresponding to the transition between comfortable and uncomfortable stimuli, thus expressing the boundary of interpersonal comfort distance.

All statistical analyses were carried out by Bayesian linear mixed models regression with the brms package (brms 2.8.0 and RStan 2.18.2, Bürkner, 2017; Gelman, Lee, & Guo, 2015), using R (version 3.5.1) and R Studio software (version 1.1.463). This method made it possible to quantify the credible parameter values of the models through their posterior distribution, given the likelihood of the data and prior information about plausible values of the parameters. The brms package uses a formula syntax similar to the lme4 package for model specification so that generalized mixed effect models can easily be specified, and interfaces with RStan to sample draws from the posterior distribution. For all the models used, we took interindividual variability into account by adding the Subject level random effects. Mildly informative prior information was given on the fixed effects by specifying a normal distribution ($M = 0$, $SD = 1$) favouring no specific direction for the effects but constraining their magnitude to reasonable value. The default priors proposed by brms (a half student-t distribution and a lkj distribution) were used for the random effects when applicable. Posterior distribution was approximated by a total of 8000 Markov chain Monte Carlo (MCMC) samples obtained from four chains, after a warm-up of 2000 samples per chain. Convergence of the MCMC chains was validated by computing the Rhat statistic and through visual inspection. Contrasts between estimates of the parameters of the posterior distribution were judged as probable when their posterior 95% Credible Intervals (CI, between 2.5% and 97.5% of the posterior distribution) did not include 0 as a probable difference. Accordingly, if the CI of a contrast includes 0, the null hypothesis cannot be rejected. Each model used for the data analysis is detailed in the following section. Data and statistical analysis are available on the OSF platform (https://osf.io/dkq3f/?view_only=d9d44db7b78a41a895f2c1129cbeb6e2).

Results

Comfort judgment of interpersonal distance

Session 1: Physiological response

A Bayesian mixed-effects regression model with a Hurdle Gamma response distribution was used to analyse the phasic driver (µS) as a function of Facial Expression (angry, happy, neutral), Crossing Distance (-8, 32, 72 cm), Subjective Emotional Intensity (0-10), Participant Gender (male, female) and Stimulus Gender (male, female), according to the model:

$$\begin{aligned} Phasic\ driver \sim\ & \text{Facial Expression} * Crossing\ Distance * SEI \\ & + Participant\ Gender + Stimulus\ gender \\ & + (1 \mid Subject) \end{aligned} \tag{21}$$

As shown in Fig. 29, data analysis revealed an interaction between Facial Expression and Crossing Distance with an increased phasic driver of 17.25E-04 µS [0.7 E-04, 34.61 E-04] for angry faces in comparison to neutral faces at the -8 cm crossing distance. Data analysis also revealed an increase in 19.73E-04 µS [0.65E-04, 42.82E-04] and 19.19E-04 µS [0.72 E-04, 41.8 E-04] for neutral faces at the 32 cm crossing distance in comparison to -8 cm and 72 cm crossing distances, respectively. Finally, we observed an interaction effect between SEI and Crossing Distance and between SEI and Facial Expression on the EDA. A greater slope due to one-point increase in SEI evaluation was observed at the -8 cm compared to the 72 cm Crossing Distance (+4.94E-04 µS [1.45E-04, 9.05E-04]), and was also observed for angry faces in comparison to neutral (+4.51E-04 µS [0.51E-04, 8.86E-04]) and happy faces (+3.79E-04 µS [0.45E-04, 7.68E-04]). No gender effect emerged for either the gender of the participants or the gender of the stimulus (+22.01 E-04 µS [-7.86, 59.59], -2.65 E-04 µS [-9.89, 4.27] respectively). The R-Squared of this fit was computed using the function bayes_R2 and revealed a coefficient of .23 [.18, .29]. Complementary data are available in appendix 1 Table A.1).

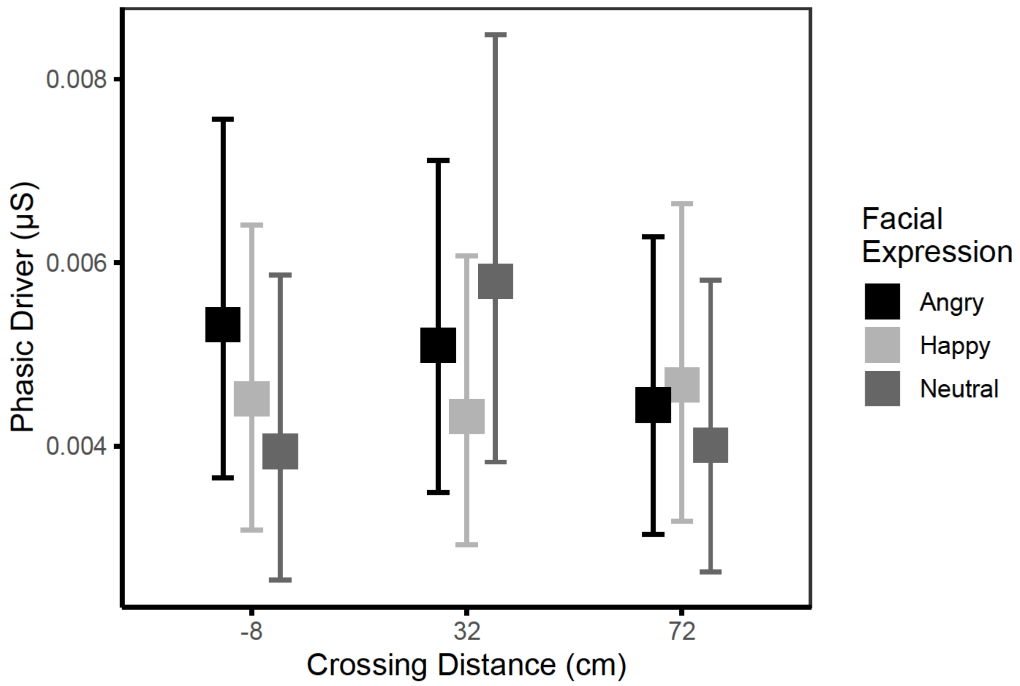

Fig. 29. Posterior mean Phasic Driver (µS) estimates and 95% CI as a function of facial expression and crossing distance for fixed mean SEI of 4.3.

Even though we used only three distances, we analysed the percentage of comfortable responses for each distance. Considering comfort judgments in session 1, a Bayesian logistic mixed-effects regression model was used with a Bernoulli distribution likelihood to analyse the probability of responding ‘comfortable’ per condition as a function of Facial Expression (angry, happy, neutral), and Crossing Distance (-8, 32 and 72 cm, as a categorical variable), according to the model:

$$(Comfortable/Not\ comfortable\ response) \sim \text{Facial Expression} * Distance + (1 \mid Subject) \quad (22)$$

The main results are reported in

Table 1 (averaged R-Squared of fit: R^2 = .56 [.54, .58]).

Table 1. Estimated percentage of 'comfortable' response (%) and 95% CI as a function of facial expression and crossing distance.

Estimate	Mean %	95 % CI
-8 cm	7.86	[5.36, 10.88]
32 cm	62.47	[56.09, 68.48]
72 cm	92.68	[89.83, 95.12]
Angry at 32 cm	41.54	[32.36, 51.18]
Happy at 32 cm	82.71	[75.33, 88.71]
Neutral at 32 cm	63.16	[53.73, 72.34]

Session 2: Behavioural response

Concerning comfort judgement of interpersonal distance, a Bayesian logistic mixed-effects regression model with a Binomial distribution likelihood was used to analyse the variation in the proportion of 'comfortable' responses per condition as a function of Facial Expression (angry, happy, neutral), Crossing Distance (-8 to 72 cm, as a continuous variable), SEI, Participant Gender (male, female) and Stimulus Gender (male, female) according to the model:

$$(Number\ of\ \text{'}Comfortable\text{'} \mid Number\ of\ trials) \sim \text{Facial Expression} * \text{SEI} * Crossing\ Distance * Participant\ Gender * Stimulus\ gender + (FE * FEI * Crossing\ Distance \mid Subject) \quad (23)$$

Once the model was fitted, the thresholds (mu threshold) and slopes (mu slope) of the logistic functions were computed at group and individual levels for Facial Expression and Facial Expression * SEI using equation (2), β being the sum of the parameters of the model interacting with the distance, and α the sum of those that do not. Posterior estimates of the boundary of interpersonal comfort distance and contrasts are reported in Table 2, and fitted functions are presented in Fig. 30 (averaged R-Squared of fit: R^2 = .78, [.78, .79]).

Table 2. Comfort distance boundary (cm) as a function of facial expression and SEI

Estimate	**Comfort distance boundary (cm)**	**95% CI**
Angry	33.12	[27.97, 38.94]
Neutral	26.68	[23.14, 30.38]
Happy	21.93	[17.79, 26.06]
Contrast Angry - Happy	*11.19*	*[6.6, 16.48]*
Contrast Angry - Neutral	*6.44*	*[3.26, 10.11]*
Contrast Happy - Neutral	*-4.75*	*[-7.68, -2.06]*
Contrast Subject Male - Female	-0.66	[-7.49, 6.15]
Contrast Avatar Male - Female	*5.52*	*[4.21, 6.94]*
Avatar Male	30	[26.02, 34.39]
Avatar Female	24.48	[20.89, 28.35]
Contrast Angry Avatar Male - Female	*5.68*	*[3.4, 8.24]*
Contrast Neutral Avatar Male - Female	*5.84*	*[4.15, 7.64]*
Contrast Happy Avatar Male - Female	*5.05*	*[3.12, 7.07]*
Trend SEI	-0.02	[-0.56, 0.53]
Trend SEI Happy	-0.83	[-1.77, 0.03]
Trend SEI Angry	*0.84*	*[0.05, 1.75]*
Trend SEI Neutral	-0.02	[-0.66, 0.63]
Trend SEI Happy - Angry	*-1.67*	*[-2.97, -0.49]*
Trend SEI Happy - Neutral	-0.81	[-1.84, 0.15]
Trend SEI Neutral - Angry	-0.86	[-1.84, 0.05]

Note: Italics represent contrasts with CI that do not overlap with zero (i.e., robust estimate with 95% CI).

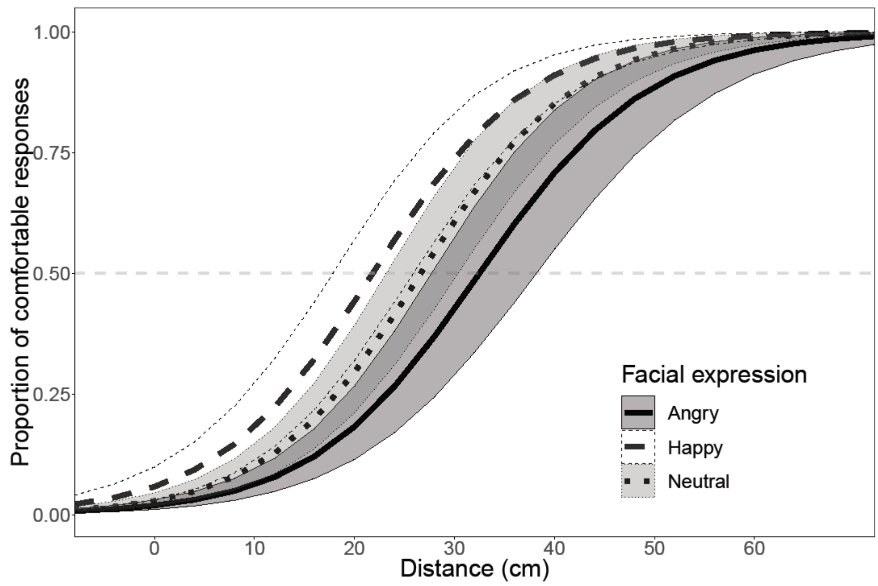

Fig. 30. Mean prediction and 95% CI of posterior distribution of proportion of "comfortable" responses per crossing distance and facial expression. Dashed grey horizontal line represents comfort distance boundary at 50%.

Reliability of measures of interpersonal comfort distance

Finally, we conducted a post-hoc validation of the measures of interpersonal comfort distance obtained in session 2 by fitting the proportion of ‘comfortable’ responses for each participant (session 1) at 32 cm (i.e., close to the boundary of interpersonal comfort distance) with respect to the boundary of interpersonal comfort distance and standard deviation (session 2) using model (23), with respect to each facial expression. To obtain the proportion of ‘comfortable’ responses at 32 cm, we fitted model (22) again but applied only the data of the 32 cm crossing distance, and used the posterior distribution of the estimates obtained from the fit. We then used the individual boundary of interpersonal comfort distance and standard deviations according to each facial expression from the posterior distribution. We removed outliers in the dataset before fitting the model (i.e., boundary of interpersonal comfort distance below 0 cm or greater than 150 cm, or when the standard deviation was greater than 1 for a total of six responses, 5.13% of the data). Finally, we used a Bayesian mixed-effects regression model with a Gaussian distribution likelihood taking measurement errors of the predictor thresholds into account (using Brms me() predictor specification), also taking into account the standard deviation according to the model:

$$Proportion\ of\ 'Comfortable'\ Responses \sim me(Boundary,\ Boundary\ SD) + (1\ |\ Subject) \tag{24}$$

As shown in Fig. 31, this analysis revealed a strong relation between the boundary of interpersonal comfort distance and the proportion of ‘comfortable’ responses at 32 cm with a decrease of 1.14% [0.82, 1.47] in the proportion of responding ‘comfortable’ per 1 cm gain in the interpersonal comfort boundary (averaged R-Squared of fit: R^2 = .44 [.31, .55]).

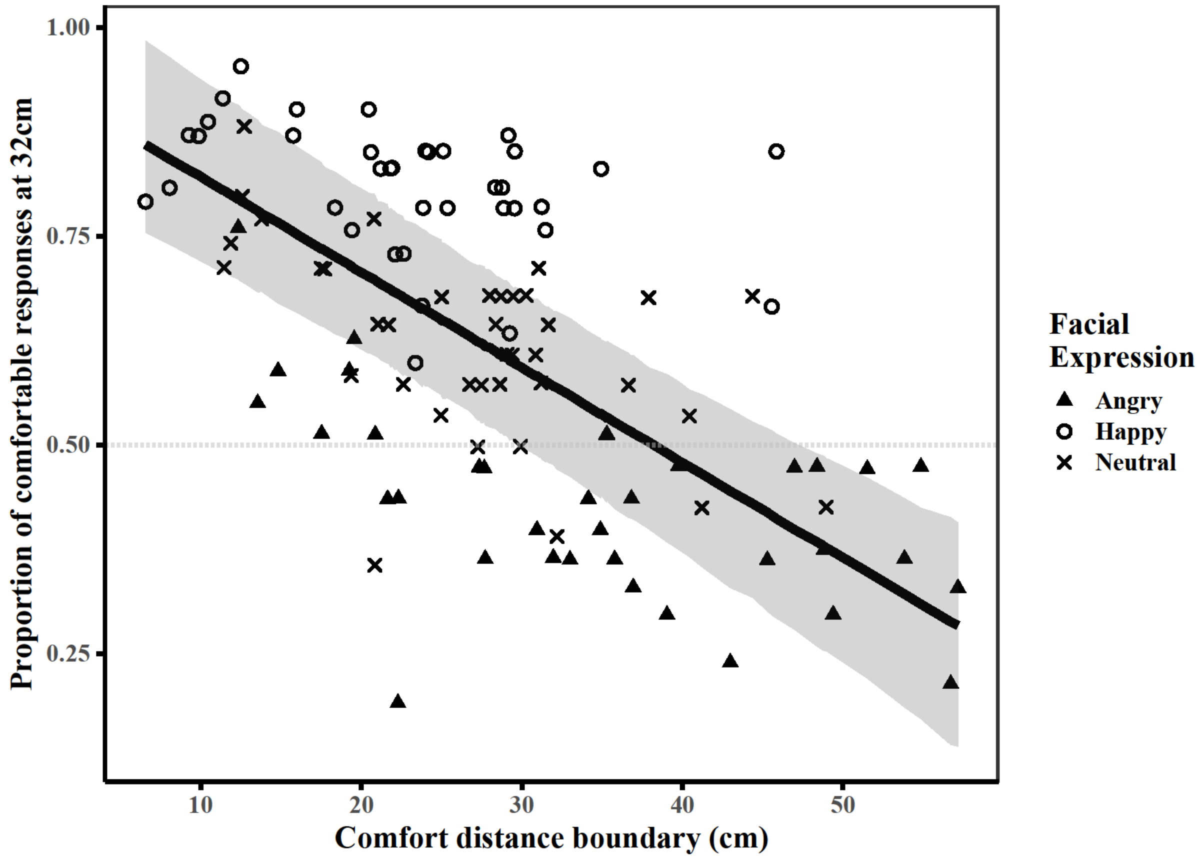

Fig. 31. Mean prediction and 95% CI of posterior distribution of proportion of 'comfortable' responses for crossing distance at 32 cm per comfort distance boundary (cm) and prior estimates of this fit. The 95% CI corresponds to boundary SD fixed to its mean (0.038). Dashed grey horizontal line represents proportion at 0.5 of 'comfortable' responses.

Discussion

We investigated the influence of being exposed to facial expressions presented at the perceptual threshold on automatic physiological response (measured through EDA) and interpersonal comfort distance assessed with human-like neutral stimuli (PLW). To reach the perceptual threshold, facial expressions associated with forward and backward visual masks were presented very quickly (16.67 ms) and with a very weak luminance (12% on average). Despite the presentation of facial expressions at the perceptual threshold, the latter had an effect on the physiological response, as revealed by EDA changes, as well as on the comfort judgment of interpersonal distance.

As regard physiological responses, an increase in EDA was observed when participants were previously exposed to an angry face, but only in the condition where the approaching PLW violated participants' interpersonal comfort space. A similar effect was not obtained when either participants were exposed to a neutral or happy facial expression, or when the approaching PLW respected participants' interpersonal comfort space. These data confirm that facial expressions, which trigger an autonomic reaction, are particularly relevant for adjusting approach-avoidance behaviours, even when not consciously perceived (Brosch et al., 2008; Phelps, Ling, & Carrasco, 2006). They also extend previous findings that a non-familiar conspecific invading social comfort space triggers defensive responses and behaviours (Kennedy et al., 2009). In addition, they provide new insights by showing that the defensive responses from the autonomic nervous system (ANS) depend considerably on facial expression, since the increase in physiological response was observed only when an angry facial expression was displayed. In addition, the increase in EDA with an angry face was observed despite the presentation of facial expressions at the perceptual threshold, making them difficult to identify, and while participants adjusted their behaviour to a neutral human-like stimulus. The latter observation is of paramount importance as it indicates that negative emotional experience associated with the observation of others' behaviour can have a detrimental effect on future social interactions, even when related to emotionally neutral conspecifics. Interestingly, the magnitude of the effect was coherent with the subjective assessment of the arousal of facial expressions, despite the difficulty of identifying it. The more arousing the angry face, the stronger the EDA and the greater the interpersonal comfort distance. Furthermore, the concurrent increase in the arousal of facial expressions and EDA was also greater when the crossing distance was -8 cm in comparison to 72 cm. These results are in line with the literature on the emotional relevance of stimuli for the ANS response. They also confirm that the arousal of facial expressions can be assessed despite the difficulty of identifying the expression

(LeDoux, 1998; Silvert et al., 2004).

As expected, no increase in electrodermal responses was found when facial expressions were followed by a PLW crossing the participants' fronto-parallel plane at, or farther than, the boundary of interpersonal comfort distance. This was true except in the condition with a neutral facial expression and when the PLW crossed the participants' fronto-parallel plane at the boundary of interpersonal comfort distance (i.e., 32 cm). Considered together with the percentage of 'comfortable' responses provided at this distance (63.16%), this surprising increase in physiological response in this experimental condition might be due to the specific difficulty encountered in this particular condition. Indeed, a neutral facial expression could be conceived as a clueless expression related to the emotional state of others, rendering the comfort distance decision more difficult for stimuli presented at the boundary of interpersonal comfort distance. Thus, participants had to judge the comfort of the crossing distance based on the PLW trajectory without any influence of the facial expression. The increase in EDA was not observed at the boundary of interpersonal comfort distance when participants were exposed to a happy or angry facial expression, as the emotional valence possibly compensated for the ambiguity of the location of the PLW with respect to the boundary of interpersonal comfort distance. In support of this interpretation, it has been shown that the electrodermal response increases as the mental load required to perform the task also increases (Nourbakhsh, Wang, Chen, & Calvo, 2012).

As regards interpersonal comfort judgments, we found that they increased with the approaching PLW when participants were previously exposed to a negative facial expression, and decreased when they were previously exposed to a positive facial expression, in comparison to neutral ones. These findings are in agreement with the effect of the valence of facial expressions on interpersonal comfort distance (Cartaud et al., 2018; Ruggiero et al., 2017). They also go further by showing that exposure to facial expressions at the perceptual threshold is sufficient to alter interpersonal comfort distance, with respect to an emotionally neutral stimulus. Interpersonal comfort distance adjustments were also dependent on the gender of the stimulus but not of the participants. They were larger when the stimuli were male than female for all three facial expressions, as often observed in the literature on proxemics (Argyle & Dean, 1965; Iachini et al., 2016; Uzzell & Horne, 2006). We also found an influence of the subjective assessment of the arousal of facial expressions, suggesting a concurrent modulation of interpersonal comfort distance by the valence of facial expressions and their subjective arousal.

Finally, comparing the proportion of comfortable responses at 32 cm with the psychophysical boundary of interpersonal comfort distance revealed a strong congruency of the data according to the facial expression, as revealed by the linear regression between the two measures. Although this finding seems quite intuitive, this linear relation underlines the fact that aware assessment of the interpersonal comfort distance provides a robust measure of the spatial component of social interactions. It also gives more strength to previous studies that used the same method in order to assess the boundary of interpersonal comfort distance, and which found a similar outcome (Cartaud et al., 2018; Quesque et al., 2017).

Considered as a whole, the data in the present study show that facial expressions, even of poor visual quality, can trigger defensive-related physiological responses with a concurrent modification of interpersonal comfort distance, even when interacting with emotionally neutral human-like stimuli. They suggest that human beings in social situations adapt their social behaviour depending on the valence and arousal of the emotion identified in others, and that social adjustments occur with changes in physiological markers. This suggests that the presence of emotional social stimuli in overcrowded hyperstimulating modern societies can influence forthcoming social interactions with neutral conspecifics, despite their poor visual quality. Further studies should assess the effect of facial expressions presented in peripheral vision, as is often the case in overcrowded social settings. Indeed, facial expressions in the visual periphery have been found to involve the retino-tectal neural pathway specifically. This pathway is known to provide information on low spatial frequency/high contrast stimuli, thus facilitating identification of human faces (e.g., Nakano, Higashida, & Kitazawa, 2013) and facial expressions (e.g., de Gelder et al., 1999).

Appendix

Table A. 1. Estimate Phasic Driver (E-04 µS) and 95% CI as a function of Facial Expression, Crossing Distance and IEF. Italics represent contrasts with CI that do not overlap with zero (i.e., robust estimate with 95% CI).

Contrast	**Estimate Phasic Driver (E-04 µS)**	**95% CI**
Angry - Neutral	4.65	[-5.98, 14.77]
Happy - Neutral	-1.28	[-12.22, 9.02]
Angry - Happy	5.93	[-2.73, 15.31]
Subject Male - Female	22.01	[-7.86, 59.59]
Stimulus Male - Female	-2.65	[-9.89, 4.27]
-8 - 32	-0.85	[-10.21, 8.54]
32 - 72	7.01	[-1.24, 16.14]
-8 - 72	6.16	[-2.23, 15.23]
Trend SEI	0.36	[-1.58, 2.36]
Angry - Neutral -8	*17.25*	*[0.7, 34.61]*
Happy - Neutral -8	5.62	[-10.66, 20.95]
Angry - Happy -8	11.63	[-3.56, 28.01]
Angry - Neutral 32	-7.44	[-29.73, 11.61]
Happy - Neutral 32	-16.71	[-40.23, 1.84]
Angry - Happy 32	9.27	[-5.46, 25.04]
Angry - Neutral 72	4.15	[-10.56, 19.11]
Happy - Neutral 72	7.29	[-8.99, 24.1]
Angry - Happy 72	-3.14	[-19.16, 11.25]
Angry -8 - 32	4.97	[-10.76, 21.2]
Happy -8 - 32	2.61	[-11.51, 17.03]
Neutral -8 - 32	*-19.73*	*[-42.82, -0.65]*
Angry -8 - 72	12.57	[-2.44, 28.87]
Happy -8 - 72	-2.2	[-18.42, 12.82]
Neutral -8 - 72	-0.53	[-15.61, 15.38]
Angry 32 - 72	7.61	[-6.71, 22.58]
Happy 32 - 72	-4.81	[-20.46, 9.97]
Neutral 32 - 72	*19.19*	*[0.72, 41.8]*
Trend SEI Happy	-0.7	[-3.35, 1.77]
Trend SEI Angry	*3.1*	*[0.26, 6.56]*
Trend SEI Neutral	-1.42	[-4.07, 1.7]
Trend SEI Angry - Happy	*3.79*	*[0.45, 7.68]*
Trend SEI Angry - Neutral	*4.51*	*[0.59, 8.86]*
Trend SEI Happy - Neutral	0.72	[-3.01, 4.08]
Trend SEI 72	-2.26	[-4.81, 0.13]
Trend SEI -8	2.68	[-0.21, 6.07]
Trend SEI 32	0.65	[-2.29, 3.79]
Trend SEI -8 - 72	*4.94*	*[1.45, 9.05]*
Trend SEI -8 - 32	2.03	[-1.74, 6.08]
Trend SEI 72 - 32	-2.91	[-6.63, 0.39]

Note: Italics represents contrasts with CI that doesn't overlap with zero (i.e., robust estimate with 95% CI).

STUDY 3

Foreword

Study 3 aimed at investigating the effect of the emotional context on IPD adjustment with neutral characters, focusing this time on contrast effect. In Study 2, FE were displayed at the perceptual threshold just before the appearance of the PLW and this altered IPD. However, FE were presented at the level of the position of the PLD's head, favoring assimilation effect of the emotional value of the emotional stimulus to the neutral stimulus (due to high spatial and temporal contiguity). This time, we wanted to investigate whether removing the emotional valence from the stimulus and putting it in the environment could impact IPD with the target characters with a neutral FE. It is well established that the emotional context alters our representation of individuals. For instance, when a contrast effect of the context is observed, neutral stimuli are judged more positive if they are presented embedded in a negative context than if they are presented embedded in a positive context.

We created an online experiment where two groups of participants judged of the valence of neutral characters (targets) after they were presented in a context with characters displaying an angry FE (group A) or a happy FE (group B). Target and contextual characters were sequentially presented on participants' screen in a random order. Then, participants performed an interpersonal judgment task with the same characters. In a second session, participants performed the same tasks but this time, the characters that formed the emotional context displayed a happy FE for group A and an angry one for group B. Since IPD depends on the valence of the stimulus, if we observed a contrast effect of the context during the evaluation of the neutral characters, we should observe congruent effects on IPD.

In parallel, we conducted a control task in which three independent groups evaluated the valence of the characters used in the main experiment. Each group was assigned a set of FE (angry, happy or neutral). The results enabled us to make predictions regarding the results we should observe in the experiment, namely, a strong contrast effect on valence judgments in the first session that should disappear in the second session.

Contrast effect of emotional context on interpersonal distance with neutral social stimuli

Cartaud, A., Lenglin, V., & Coello, Y. (in prep).

Abstract

Previous studies have underlined the relation between emotional valence of social stimuli and judgment of appropriate interpersonal distance (IPD). We investigate whether contrast effect of emotional context on valence judgments (Parducci, 1988) also affects judgments of IPD. In an online experiment, 51 participants were presented with successive male and female virtual characters displaying either a neutral (2 characters) or emotional (10 characters) facial expressions (FE, angry or happy). After each presentation, participants rated the (positive-negative) valence of neutral and emotional characters and provided judgments of appropriate IPD with characters presented at different distances. Classical contrast effect was observed on valence judgment, while mildly altering judgments of appropriate IPD. This suggests that although emotional context influences valence judgments of social stimuli, it has a weak effect on IPD judgments which relies predominantly on categorical information of FE.

Keywords: range-frequency model, interpersonal distances, facial expression, contrast effect, valence, social interaction, emotional context

Introduction

Since Hall (1966), particular attention has been given on the different factors responsible for the automatic adjustment of interpersonal distances (IPD), which implies a subtle balance between the need to approach conspecifics to interact efficiently with them, and the need to maintain a certain margin of safety from them to preserve body integrity (Lloyd, 2009; Siegman & Feldstein, 2014). Accordingly, a too short IPD triggers discomfort and associated neuro-physiological responses (Cartaud, Ott, Iachini, Honoré, & Coello, 2020; Cartaud et al., 2018; Evans & Wener, 2007; Kennedy et al., 2009; Vieira et al., 2019). Furthermore, the representation of near-body action space (Quesque et al., 2017), or personal factors such as age, gender and facial expression (Iachini et al., 2016; Ruggiero et al., 2017), can alter IPD adjustment. As such, facial expressions (FE) constitute crucial cues in social interactions and thus in the adjustment of IPD because they are a valuable resource of information regarding the emotional state of others (Schrammel et al., 2009). Hence, IPD increases when conspecifics display an angry FE whereas it decreases when they display a happy FE. (Cartaud et al., 2020, 2018; Ruggiero et al., 2017; Vieira, Tavares, Marsh, & Mitchell, 2017). The adjustment of IPD also correlates with both the strength of the neuro-physiological response triggered by social stimuli and the evaluation of their subjective valence (Cartaud et al., 2018; Vieira et al., 2019, 2017). Furthermore, neurological or psychopathological disease associated with socio-emotional deficits significantly affect the adjustments of IPD (Kosonogov et al., 2017; Nandrino et al., 2017; Welsch et al., 2018). The processing of emotional information conveyed by others, in particular their (positive-negative) valence, is thus of paramount importance for the adjustment of IPD in social context (Cartaud et al., 2018; Ruggiero et al., 2017).

In this outlook, a substantial literature has highlighted that judgement (or feeling) of stimulus' emotional value depends also on the emotional information conveyed by the context in which the stimulus is embedded (Mumenthaler & Sander, 2012; Russell & Fehr, 1987; Unkelbach & Fiedler, 2016; Von Neumann & Morgenstern, 1944; Wedell & Parducci, 1988; Wieser & Brosch, 2012). As pointed out in many different fields of research, judgment of stimulus' emotional value seems thus to refer to relative rather than absolute information, depending on context influence (Clark, Frijters, & Shields, 2008; Furl, 2016; Kahneman & Tversky, 1979; Kontek & Lewandowski, 2018; Louie et al., 2013).

The notion of context is usually defined according to two dimensions: a temporal and a spatial dimension (Louie et al., 2011). The spatial dimension of the context depends on the stimuli presented concurrently with the target, whereas the temporal dimension of the context depends on the sequence of stimuli presented across time (Louie et al., 2011). With temporal context, salient information and explicit judgment tasks usually promote contrast effects (Kobylínska & Karwowska, 2014; Martin et al., 1990), which refers to a negative correlation between the judgment of the target and the value of the context (Schwarz & Bless, 2007), and which decays over time (Louie et al., 2011; Wedell, Hayes, & Kim, 2020). Thus, mildly attractive faces of women are judged more (less) attractive when presented in a context of low (high) attractive women (Wedell et al., 1987). Among the models predicting contrast effect, the Range-Frequency model (RF, Parducci, 1965) proved to be particularly relevant (Wedell et al., 2020, 1987; Wedell & Parducci, 1988). RF model is based on range and frequency principles. According to the range principle, judgement of a target stimulus depends on its location relative to the two extreme values of the stimuli encountered so far (i.e., the boundaries of the context). According to the frequency principle, judgement of a target stimulus depends on the target rank within the distribution of the different values of the stimuli encountered so far. It is assumed that when judging the value of a stimulus, individuals make a compromise between the range principle and the frequency principle that might conflict if considered together in a case of a skewed distribution of contextual stimuli. Depending on individual characteristics, one principle can receive more weight than the other (Parducci, 1965).

Although the manipulation of the emotional context, leading to contrast effects, has been widely investigated in the field of emotional judgments (see Wieser & Brosch, 2012 for a review), it is not yet known whether this contrast effect would alter judgments of IPD. Our rational was as follows: if preferred IPD is driven by the valence of a stimulus, then altering its valence by manipulating the emotional context should in turn impact IPD adjustment relative to the stimulus. To address this issue, we designed an online experiment where virtual characters with neutral FE (targets) were presented within a temporal social context made up of characters with different FE (happy or angry). The social context consisted in presenting, singly, neutral and emotional characters before providing a judgment of their emotional valence. Contrast effect was tested by analyzing the effect of the range and frequency of contextual emotional characters on valence ratings and IPD judgment of neutral characters. According to the RF theory, if the values of the contextual characters are unimodal (e.g., negative characters), the neutral character will be attributed a value dragged toward the values opposite to that of the context (e.g., more positive valence than its objective value). However, if the context is multimodal (e.g., negative and positive characters, equally represented across time), the value attributed to the neutral character should be repelled by both edges of the context and thus neighbor to the central rank and range. Therefore, as IPD depends on the subjective valence of the character (Cartaud et al., 2018), preferred IPD should be altered by the context manipulation.

Method

Participants

Fifty-one adult volunteers completed the entire online experiment (39 women, Mage = 30.40, SDage = 9.7, M_{study} =4, SD_{study}= 2.55 after the French baccalaureate). Based on GPower (version 3.1, within-between ANOVA α =0.05, Cohen's F = 0.25), the requested sample size was 36 participants, but we decided to increase the number of participants because the experiment was completed online. All of the participants had normal vision or were invited to use optical correction (e.g., wear glasses), if they consented to take part in the experiment. Validated informed consent was obtained from each participant before continuing the experiment, the protocol received approval by the local institutional ethics committee (2020-426-S83).

Apparatus and stimuli

The experiment was created on lab.js builder (Henninger, Shevchenko, Mertens, & Kieslich, 2019), hosted and run online on the CNRS web server. Advertisement was shared on social and professional networks. The stimuli consisted of 14 male and 14 female characters selected from the ATHOS database (Cartaud & Coello, 2020). Two male and two female characters displayed a neutral FE (targets), five males and five females displayed an angry FE and the last five of each gender displayed a happy FE (context). Both the characters and the empty room in which they were presented were built on Unity (2018.2.21f1 version, Fig. 32).

Depending on the task, the characters could be presented at different distances from the participants that had to represent themselves being at the level of the proximal side of the virtual room. Those distances varied from 25 to 135 cm from this proximal side of the virtual room (thus, from the position of the participants). The increment from 25 to 85 cm was of 6 cm and of 10 cm from 85 to 105 cm thus resulting in a total of 16 different distances. This selection was to minimize the number of trials while kipping the increment as small as possible, allowing us to experimentally scan a reasonable range of distances.

Procedure and design

After having completed a short questionnaire focusing on general information (age, gender, study level, sight), participants performed three tasks twice (once per session, Fig. 32).

Each participant was randomly assigned to one of the two groups that differed only in the order of presentation of the emotional context. For group A (N= 23), the emotional context of the first session consisted of angry characters (negative unimodal context) and that of the second session consisted of happy characters (positive and multimodal context due to previous exposition to the other emotion). The pattern was reversed for group B (N = 28, session 1 consisted of happy contextual characters, session 2 consisted of angry contextual characters). For each participant, the pair of neutral characters (one male and one female) was randomly assigned to each session.

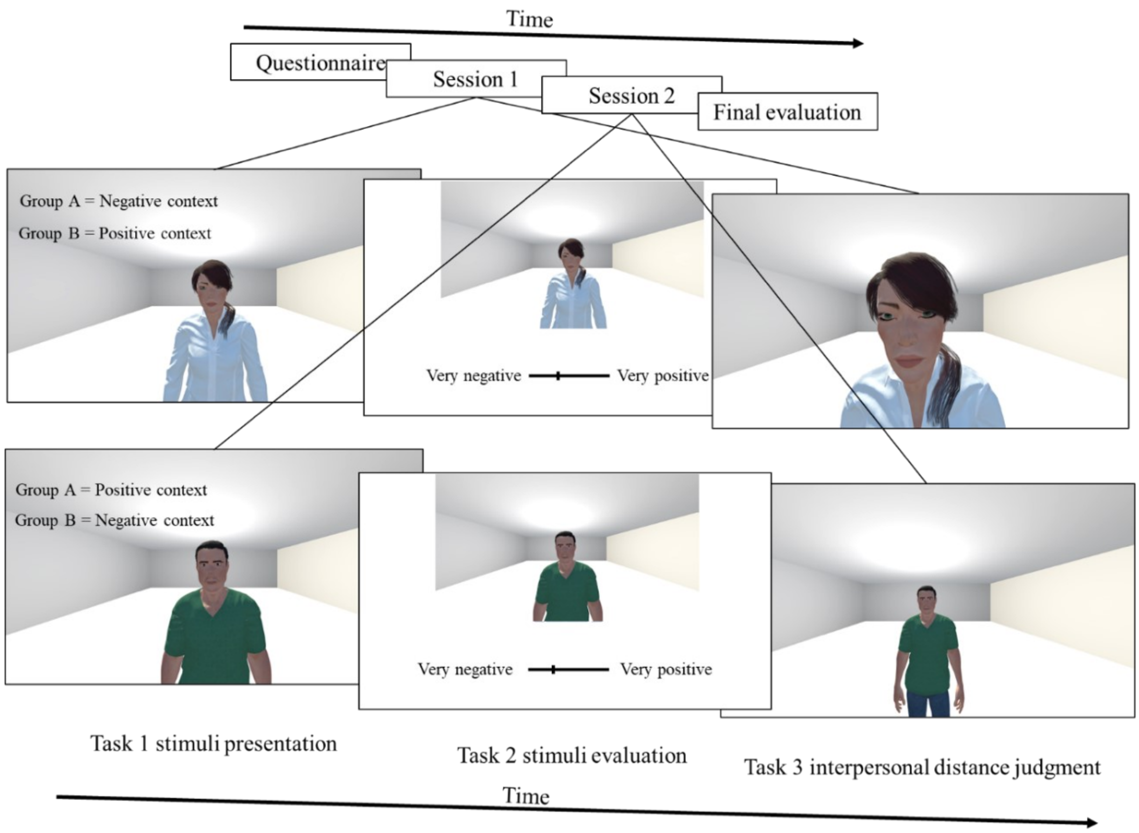

Fig. 32. Schematic representation of the experimental course (on the top) and of the sessions (bottom part).

In the first task, the context was settled up using 10 emotional characters (happy or angry depending on the session) and 2 neutral characters (one of each gender). Since (i) the neutral stimuli were at the edges of the range (neutral characters have either the minimum or the maximum valence rating depending on the context) and (ii) the distributions of stimuli were skewed (context was either mostly negative or mostly positive), the RF model predicted a strong contrast effect. Participants passively but carefully observed successive pictures of the characters. Each character was presented twice in a random order for 2 secs at 61 cm from the proximal side of the room in full screen mode. A white screen appeared during 500 ms between each character presentation.

In the second task, participants sequentially evaluated two emotional characters (one male and one female), selected among the characters who were the most valenced when displayed with a neutral face (positively or negatively), according to ATHOS database (Cartaud & Coello, 2020) and the two neutral ones. We chose to limit the amount of contextual characters evaluation in order to prevent the online experiment extending to much (thus reducing the number of quits). The characters were displayed at 61 cm from the proximal side of the room and the picture filled 60% of the computer screen. Below the picture was positioned a slider question for the evaluation of the valence of the characters. Participants had to position a cursor along the horizontal line using the computer trackpad or mouse (10 units) with the labels "very negative" on the left side and "very positive" on the right side of the slider. No numerical feedback of their rating was provided.

The third task consisted in judging whether the distance between the participant and the character was appropriate for social interaction or not (IPD judgment). The same characters as in the previous task (two neutral and two emotional characters) were presented singly and randomly at a distance varying from 25 to 135 cm. Participants had to respond as fast and as spontaneously as possible by pressing the "L" (appropriate) or "S" (inappropriate) keys of their keyboard. The characters remained on the screen until the participant's response was provided, then followed by a white screen lasting 500 ms. Each character pseudo-randomly appeared four times at each distance (Gender of the character [2] * FE [2] * Distance [16] * Repetition [4]).

The first half of the trials consisted in two full repetitions of the trials presented in a random order (4 characters at the 16 distances presented twice). A break was proposed after this first half then, the 128 last trials were randomly administered. Participants started with a 6-trial training session with characters not used in the experiment in order to operationalize the association between responses and computer keys.

After this first (unimodal) session, a break was proposed before starting the second (multimodal) session that consisted in the same three tasks, but with the other emotional context and two new characters displaying a neutral FE. Thus, during this second session, the contextual characters had a happy FE for group A and an angry FE for group B. After these two sessions, participants completed a post-experimental evaluation of the characters with a neutral FE only (the targets).

Control task

During a control task, another set of 20 participants performed the valence ratings of the neutral characters used in the main experiment. One of them was discarded because he/she didn't move the sliders while completing the evaluation (N= 19, 9 women). The characters assessed consisted in the four target characters with the neutral FE (two males and two females). As in the main experiment, the characters were first sequentially presented, then participants rated their valence as in task 2 (very negative/very positive). This control task aimed at quantifying the contextless ratings of the neutral characters.

Data analysis

Statistical analyses were carried out using Bayesian linear mixed models' regressions (brms 2.13.5 and RStan 2.21., Bürkner, 2017; Gelman, Lee, & Guo, 2015), with R (version 4.0.2) and R Studio software (version 1.3.1056). The main independent variables of interest were the FE of the target stimuli (angry, happy, neutral), the FE of the context stimuli (negative, positive), the session (unimodal, multimodal), and their combination. We focused on the contrast between eight combinations (angry negative unimodal, angry negative multimodal, happy positive unimodal, happy positive multimodal, neutral negative unimodal, neutral negative multimodal, neutral positive unimodal and neutral positive multimodal). More specifically for every task, we analyzed the contrasts between:

- Neutral negative unimodal – neutral positive unimodal (*unimodal* context effect)
- Neutral negative multimodal – neutral positive multimodal (*multimodal* context effect)
- Neutral negative unimodal – neutral negative multimodal (context effect *between* the sessions)
- Neutral positive unimodal – neutral positive multimodal (context effect *between* the sessions)

In addition, we compared the valence ratings of the neutral stimuli (negative and positive context, unimodal and multimodal session) to the post-experimental valence ratings (obtained after the two sessions) to test for the *stability* of the judgments over the experiment. We also compared the neutral stimuli to the ratings obtained by the control group to quantify the effect of *emotional* context. Finally, we tested for gender effect of the participants and the characters for the IPD judgment but controlled these effects for the *unimodal, multimodal* and *between* analysis of the valence ratings.

For every model, we considered interindividual variability by adding the Subject level random effect, which was required because the experiment was performed online. We specified a mildly informative normal distribution on the fixed effects (constraining the magnitude of the effects to reasonable values without specific direction) and used the default brms priors for the random effects when applicable (half student-t distribution and a lkj distribution). The approximation of the posterior distribution was obtained through 8000 Markov chain Monte

Carlo (MCMC, 4 chains of each 2000 warm-up samples), whose convergence was validated through visual inspection and by computing the Rhat statistic. The Credible Intervals (CI) were fixed at 95% to judge contrasts between estimates of the parameters of the posterior distribution as probable.

For each condition, the IPD boundaries were determined from the participant's appropriate/inappropriate response at each distance with:

$$y = \frac{e^{(\alpha + \beta X)}}{1 + e^{(\alpha + \beta X)}} \qquad (25)$$

where y is the participants' response and take the value 1 if the participant considers the distance as appropriate and 0 otherwise, X is the distance. From this equation, we computed the ratio $-\alpha/\beta$ giving the critical value of X corresponding to the transition between appropriate and inappropriate responses, (i.e., the preferred IPD).

Data and statistical analysis are available on the OSF platform (https://osf.io/dur4k/?view_only=0199de84522546cf96289c434f7e928f).

Results

For every task, the estimates and their 95% CI are reported in Table 3 and the contrasts of interest listed in the data analysis section are reported in Table 4.

Table 3. Posterior estimates and 95% CI for every parameter evaluated: valence (during the experiment, during the post-experimental evaluation and of the control group, out of 10) and appropriate distance threshold (cm) as a function of the Stimulus FE depending on the Context and the Session and as a function of the gender of the participant and of the character

Parameter	**Stimulus**	**Context**	**Session**	**Mean**	**95% CI**
Valence	Angry	Negative	Unimodal	0.85	[0.51; 1.2]
	Angry	Negative	Multimodal	1.51	[1; 1.99]
	Happy	Positive	Unimodal	7.63	[7.21; 8.05]
	Happy	Positive	Multimodal	7.95	[7.27; 8.61]
	Neutral	Negative	Unimodal	6.41	[5.85; 6.96]
	Neutral	Negative	Multimodal	5.31	[4.93; 5.7]
	Neutral	Positive	Unimodal	2.81	[2.25; 3.38]
	Neutral	Positive	Multimodal	4.56	[4.02; 5.1]
Valence post-experimental evaluation	Neutral	Negative	Unimodal	4.97	[4.11; 4.97]
	Neutral	Negative	Multimodal	6.06	[5.12; 6.06]
	Neutral	Positive	Unimodal	5.32	[4.19; 5.32]
	Neutral	Positive	Multimodal	4.62	[3.48; 4.62]
Valence Control	Neutral	Control		4.59	[4.04; 5.15]
Appropriate distance threshold	Angry	Negative	Unimodal	58.51	[50.95; 67.36]
	Angry	Negative	Multimodal	60.75	[51.39; 72.4]
	Happy	Positive	Unimodal	47.78	[42.13; 54.53]
	Happy	Positive	Multimodal	44.38	[38.22; 51.67]
	Neutral	Negative	Unimodal	48.39	[40.71; 57.19]
	Neutral	Negative	Multimodal	46.95	[40.54; 54.65]
	Neutral	Positive	Unimodal	53.33	[46.67; 61.17]
	Neutral	Positive	Multimodal	50.44	[43.09; 59.02]
	Subject Male			54.86	[45.71; 65.44]
	Subject Female			50.34	[44.53; 57.36]
	Stimulus Male			52.09	[46.39; 59.03]
	Stimulus Female			50.72	[45.32; 57.17]
	Valence			*-0.82*	*[-1.23; -0.43]*
Appropriate distance slope	Angry	Negative	Unimodal	3.9	[3.31; 4.47]
	Angry	Negative	Multimodal	3.64	[2.98; 4.29]
	Happy	Positive	Unimodal	4.44	[3.82; 5.04]
	Happy	Positive	Multimodal	4.79	[4.12; 5.45]
	Neutral	Negative	Unimodal	4.16	[3.53; 4.82]
	Neutral	Negative	Multimodal	4.16	[3.53; 4.8]
	Neutral	Positive	Unimodal	4.15	[3.54; 4.75]
	Neutral	Positive	Multimodal	4.38	[3.74; 5.04]

Note: Italics indicate a credible effect of the valence ratings on the appropriate distance estimate contrasts with CI that doesn't overlap with zero (i.e., robust estimate with 95% CI).

Table 4. Context effects between the estimates and 95% CI for every parameter evaluated: valence (during the experiment, during the post-experimental evaluation and for the control group, out of 10) and appropriate distance threshold (cm). Gender effects (of participants and of the characters) are also reported for the appropriate distance threshold

Parameter	Effect	Estimate 1	Estimate 2	Contrast	95% CI
Valence	Unimodal	*Neutral Negative Unimodal*	*Neutral Positive Unimodal*	*3.6*	*[2.81; 4.39]*
	Multimodal	*Neutral Negative Multimodal*	*Neutral Positive Multimodal*	*0.75*	*[0.09; 1.42]*
	Between	*Neutral Negative Unimodal*	*Neutral Negative Multimodal*	*1.1*	*[0.42; 1.77]*
		Neutral Positive Unimodal	*Neutral Positive Multimodal*	*-1.75*	*[-2.52; -0.96]*
Valence post-experimental evaluation	Stability	*Neutral Negative Unimodal*	*Neutral Negative Post*	*2.36*	*[1.38; 2.36]*
		Neutral Negative Multimodal	Neutral Negative *Post*	0.18	[-0.71; 0.18]
		Neutral Positive Unimodal	*Neutral Positive Post*	*-1.5*	*[-2.39; -1.5]*
		Neutral Positive Multimodal	Neutral Positive *Post*	0.99	[0; 0.99]
Valence Control	Emotional effect	*Neutral Negative Unimodal*	*Neutral Control*	*1.81*	*[1.01; 2.61]*
		Neutral Negative Multimodal	Neutral Control	0.64	[-0.1; 1.39]
		Neutral Positive Unimodal	*Neutral Control*	*-1.74*	*[-2.58; -0.94]*
		Neutral Positive Multimodal	Neutral Control	-0.02	[-0.83; 0.8]
Appropriate distance threshold	Unimodal	Neutral Negative Unimodal	Neutral Positive Unimodal	-4.94	[-13.26; 3.44]
	Multimodal	Neutral Negative Multimodal	Neutral Positive Multimodal	-3.49	[-11.61; 4.53]
	Between	Neutral Negative Unimodal	Neutral Negative Multimodal	1.44	[-6.85; 9.98]
		Neutral Positive Unimodal	Neutral Positive Multimodal	2.89	[-5.16; 10.76]
	Gender	Subject Male	Subject Female	4.52	[-4.43; 14.14]
		Stimulus Male	*Stimulus Female*	*1.37*	*[0.67; 2.14]*
	Emotion	*Angry Negative Unimodal*	*Neutral Negative Unimodal*	*10.13*	*[3.98; 16.19]*
		Happy Positive Unimodal	*Neutral Positive Unimodal*	*-5.55*	*[-9.16; -2.12]*
		Angry Negative Unimodal	Neutral Positive Unimodal	5.18	[-2.17; 12.68]
		Happy Positive Unimodal	Neutral Negative Unimodal	-0.61	[-8.73; 7.39]

Note: Italics represents contrasts with CI that doesn't overlap with zero (i.e., robust estimate with 95% CI).

Valence ratings

Concerning the valence rating of the experimental evaluation, we performed a linear regression with a normal distribution as a function of Stimulus FE (angry, happy, neutral), Context (negative, positive), Session (unimodal, multimodal), Participant's gender (male, female) and Stimulus' gender (male, female). The R-Squared of the fit for the valence ratings was computed using the function bayes_R2 and revealed a coefficient of 0.85 [0.83; 0.87]. The main effects are represented in Fig. 33.

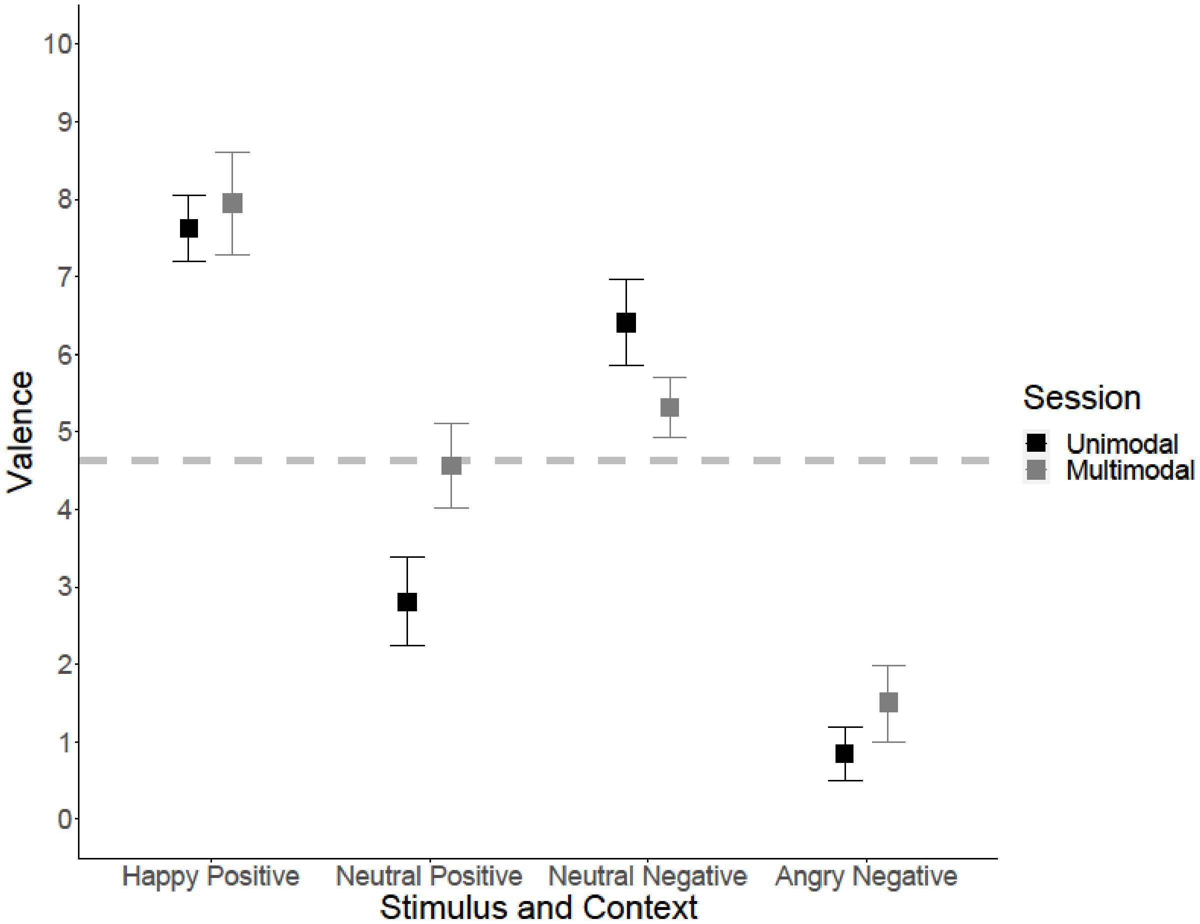

Fig. 33. Graphical representation of the posterior mean valence and the 95% CI as a function of stimulus FE, context and session. Grey horizontal line represents the average rating of neutral targets obtained by the control group (4.59/10).

Then, we performed a second analysis to test the stability of the ratings over the entire experiment. To do so, we took into account the valence ratings obtained during the experimental evaluation of each neutral character (unimodal and multimodal session) and compared it to the ratings obtained during the post-experimental evaluation (of the four neutral characters), after the two sessions (Fig. 34, averaged R-Squared of fit: R^2 = 0.78 [0.76; 0.8]). Lastly, we performed a last analysis to compare the valence ratings obtained during the experimental evaluation of the neutral characters with those obtained by the control group (Fig. 34, averaged R-Squared of fit: R^2 = 0.54 [0.45; 0.6]). As presented in Table 4, only the ratings performed in the unimodal session differed from both the post-experimental evaluation and from the ratings provided by control group.

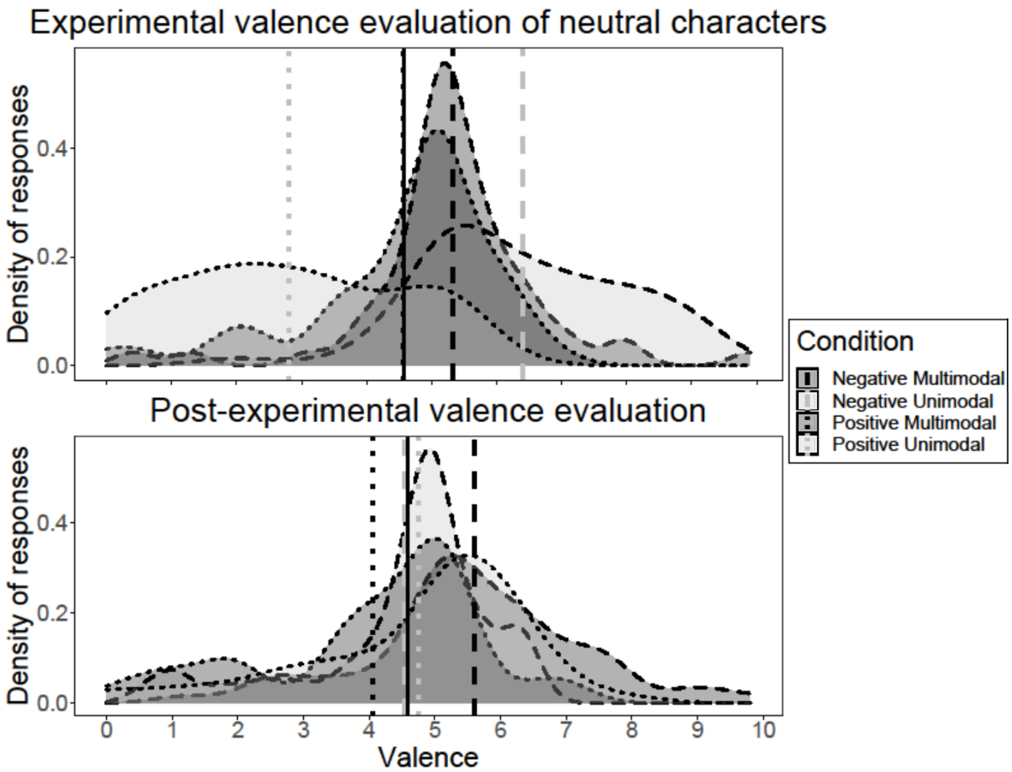

Fig. 34. Density of responses of the valence ratings for the neutral characters during the experiment (top) and the post-experimental session (bottom). Vertical lines represent the average rating of each condition (context – negative, positive – and session – unimodal, multimodal). Solid dark lines represent the average valence rating obtained by the control group.

Interpersonal distances

Concerning the analysis of IPD, we used a logistic regression with a binomial distribution likelihood. First, we analyzed the variation of the proportion of "appropriate" responses per condition as a function of Stimulus FE (angry, happy, neutral), Context (negative, positive), Session (unimodal, multimodal), Participant's gender (male, female), Stimulus' gender (male, female) and Valence (evaluation obtained during the second task of the unimodal session). Then, the thresholds (mu threshold) and slopes (mu slope) of the fits were computed at the group level for each Stimulus FE (angry, happy, neutral), Context (negative and positive), Session (unimodal, multimodal), Valence ratings and stimulus' Gender (male, female). As reported in Table 2 and presented in Fig. 35, no contrast effect emerged, but each 1-point increase in valence lead to a decrease in IPD of almost 1 cm (-0.82 cm [-1.23; -0.43], averaged R-Squared of fit: R2 = 0.91 [0.90; 0.91].

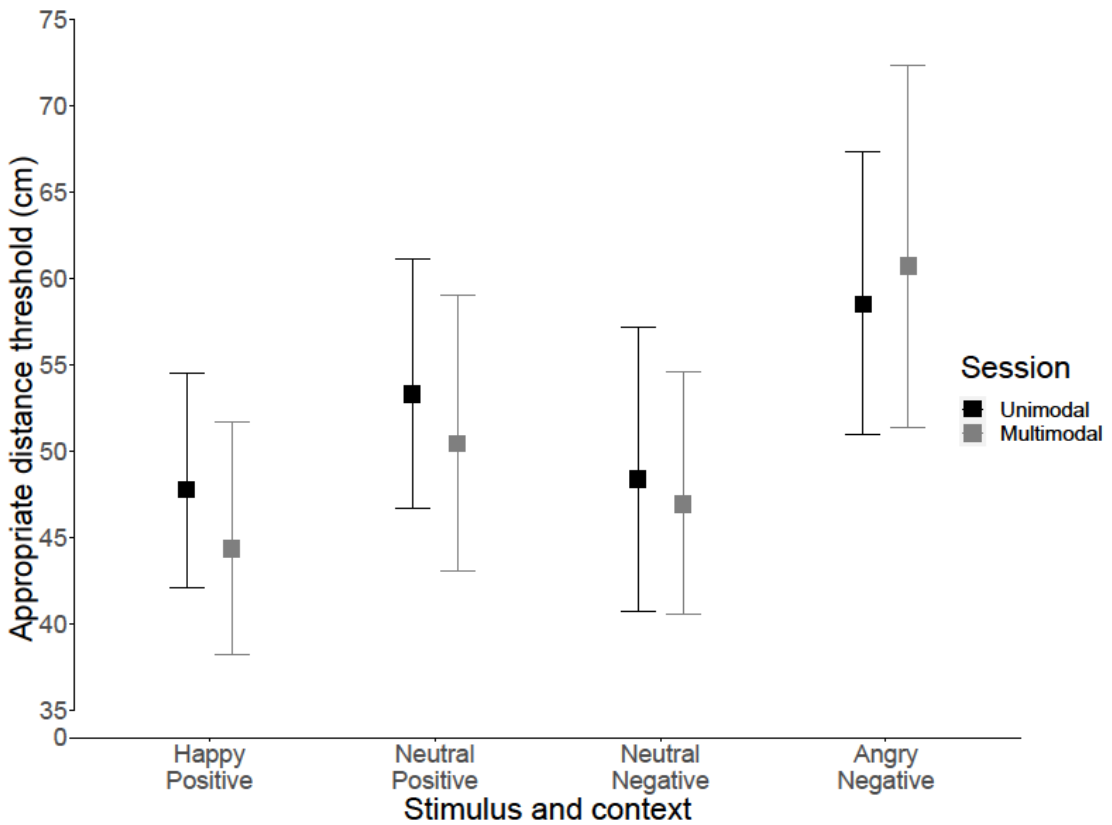

Fig. 35. Mean prediction and 95% CI of posterior distribution of "appropriate" distance thresholds per stimulus, context and session.

Post-hoc analysis

To further analyze the contrast effect on IPD, we decided to conduct post-hoc analysis for the unimodal session only. More precisely, we investigated whether contrast effect, would emerge when comparing preferred IPD with the neutral characters of each context to preferred

IPD with the emotional characters from each context. (Table 2, see effect emotion for appropriate distance threshold parameter). First, we observed that preferred IPD with the neutral characters differ from preferred IPD with the characters forming their context (within subject). Preferred IPD was larger with angry characters than with neutral characters embedded in the same negative context (+ 10.13 cm, [3.98; 16.19]) and preferred IPD was shorter with happy characters than with neutral characters embedded in the same positive context (-5.55 cm [-9.16; -2.12]). Second, preferred IPD with the neutral characters did not credibly differ from preferred IPD with the emotional characters from the other context (between subject). More precisely, preferred IPD with angry characters was not credibly different from neutral characters embedded in the positive context (+5.18 cm [-2.17; 12.68]) and similarly, preferred IPD with happy characters was not credibly different from that with neutral characters embedded in the negative context (-0.61 cm [-8.73; 7.39]). Therefore, even if the classical contrast effect was not observed on IPD adjustment when comparing the neutral characters' preferred IPD of each context, the above analysis revealed that the emotional context specifically altered preferred IPD with the neutral characters.

Discussion

In social contexts, evidence suggests that IPD adjustment is dependent on the affective value of conspecifics; the more positive the conspecifics the shorter the IPD; the more negative the conspecifics the larger the IPD (Cartaud et al., 2018; Fini et al., 2020; Ruggiero et al., 2017; Vieira et al., 2019). However, it has been highlighted that judging the affective dimension of others also depends on the emotional context (Wedell & Parducci, 1988). More precisely, a contrast effect (negative correlation between the judgment of a neutral target and the value of the context) which can be formalized by the range-frequency model, was reported (Parducci, 1965; Wedell & Parducci, 1988). Here, we aimed at investigating whether the changes in valence of a neutral character, induced by an emotional context (positive or negative characters) could lead to congruent changes in IPD adjustments. First, and in line with previous studies, we observed contrast effects on valence ratings of virtual characters with a neutral FE when presented sequentially with a unimodal emotional context (negative or positive). Thus, neutral characters were judged more positive when presented in a context with angry characters than those presented in a positive context (Wedell & Parducci, 1988). Second, and also predicted by the RF model, when participants were first exposed to an emotional context (e.g., positive), then to another context with an opposite valence (e.g., negative), their judgments of a new set of neutral targets was influenced by both contexts (Parducci, 1965). Thus, neutral characters from the negative multimodal context (second session) only slightly differed in terms of valence from those of the positive multimodal context. Interestingly, when comparing the valence rating obtained in the experiment to those obtained in the post-experimental evaluation or reported by the control group, no difference emerged for the multimodal sessions. This suggests that both contexts equally influenced the neutral targets rating resulting in an average value. These results can jeopardize the notion of temporal decay of the influence of previously encountered stimuli on valence judgments (Louie et al., 2011). Indeed, according to Louie et al. (2001), the weight given to each contextual information in the evaluation of a stimulus decays with time, which is not the case in the present study since the contextual characters from both the unimodal and the multimodal session impacted the valence ratings of the neutral characters.

However, contrary to our hypothesis, no credible classical context effect was observed on IPD adjustment with the neutral characters, even if the direction of the modulation of IPD was congruent with the changes in valence. One possible explanation could be related to the need for explicit and simple judgments of the value of the target for contrast effect to be observed (Kobylínska & Karwowska, 2014; Martin et al., 1990; Wedell & Parducci, 1988). Indeed, previous studies revealed the subtility of this effect and that contrast effect can be suppressed using very large rating scales (Wedell & Parducci, 1988) or during double task procedures (Martin et al., 1990). Thus, our experimental procedure (method of constant stimuli) borrowed from psychophysics might be too complex to let emerge strong comparison strategies leading to contrast effect. Hence, it would be worth testing whether contrast effects emerge with simpler method such as stop-distance paradigm. If so, the present results might challenge the robustness of contrast effect of the context (Kobylínska & Karwowska, 2014; Unkelbach & Fiedler, 2016).

Another explanation, possibly also challenging the robustness of contrast effect, might be related to the intensity of the emotional context. Indeed, the characters only displayed emotional faces which might not lead to a sufficiently strong contrast effect to alter IPD adjustment with the neutral characters. Characters with a whole emotional body-posture might lead to higher perceived intensity of the valence and thus, to stronger effect of the context (Wieser & Brosch, 2012). In line with this latter statement, it should be noted that the valence had a relatively small impact on the adjustment of IPD. The negative relation between the valence ratings obtained during the unimodal session (task 2) and IPD adjustment was quite smooth, as one-point increase in valence led to a decrease of only 0.82 cm of IPD. Moreover, in a previous experiment, we did not observe significant differences in IPD adjustment with approaching characters displaying either a positive or a neutral FE but with a neutral gait (Cartaud et al., 2018).

Despite the lack of direct contrast effect on IPD adjustment, we observed that IPD with neutral characters (negative and positive contexts) differed from that with emotional characters of their context (angry and happy characters respectively) but not from that with emotional characters of the other context (happy and angry characters respectively). Therefore, IPD with neutral character was specifically altered by the emotional context in the direction of a contrast effect, although subtly, which may explain why it was not directly observable when comparing the neutral characters. This finding echoes the subtle effect of valence on IPD adjustment and support the hypothesis that IPD adjustment in social context is only weakly dependent on the (positive-negative) valence dimension of the FE but mostly dependent on the category of the emotional FE (Cartaud et al., 2020, 2018; Ruggiero et al., 2017). This interpretation could in part explain why IPD adjustment was only mildly sensitive to context effect.

Overall, the present study validates the well-known contrast effect of the contextual valence but questions its robustness when tackling more subtle and implicit judgments. Indeed, valence judgment of neutral individuals depends on their emotional context but this effect only mildly altered judgments of appropriate IPD. Further investigations will be needed to find out whether the weak contrast effect on IPD is due to the general weakness of contextual effect or to immutable representations of emotional category, receiving more weight than the valence dimension. If receiving more support, the present findings may challenge theories suggesting either a full relative-dependency or a full absolute-dependency of emotional judgments, by rather suggesting a more hybrid dependency of IPD adjustments on emotional information.

STUDY 4

Foreword

Study 4 was conducted and written at the end of the French lockdown that started on Marsh 2020. During this period, social distancing was (and still is) part of the barrier gestures to adopt in order to limit the spread of the virus, even more since wearing a face mask was not mandatory yet, studying IPD seemed thus relevant. In addition, we studied how IPD adjustment was modulated by a physical characteristic that was not the emotional facial expression: the wearing of a face mask. Indeed, just before the end of the lockdown, we ignored how wearing a face mask would affect threat perception; it could either be perceived as a safety cue ("if this individual is wearing a face mask, he/she protects me from Covid-19") or be perceived as a reminder of the pandemic context ("he/she wears a face mask because of Covid -19 so I have to respect barrier gestures and maintain my distance from him/her"). During an online experiment, characters successively appeared on participant's computer screen at different distances from them in an empty room. They wore a face mask, or wore no mask but displayed an angry, neutral or happy emotional facial expression. Participants had to estimate whether the distance between themselves and the character was appropriate for social interaction or not. After this task, participants had to evaluate the characters in terms of threat, determination, trust and health. Results are presented in the following section. We also intend to repeat this experiment in order to study whether and how individual's behavior changes with time regarding IPD adjustments related to face mask.

Wearing a face mask against COVID-19 results in a reduction of social distancing

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Preprint: https://psyarxiv.com/ubzea/

Abstract

In the context of the Covid-19 pandemic, barrier gestures such as regular hand-washing, social distancing, and wearing a face mask are highly recommended. Critically, interpersonal distances (IPD) depend on the affective dimension of social interactions, which might be affected by the current Covid-19 context. In the present internet-based experimental study, we analyzed the preferred IPD of 457 French participants when facing human-like characters that were either wearing a face mask or displaying a neutral, happy or angry facial expression. Results showed that IPD was significantly reduced when characters were wearing a face mask, as they were perceived as more trustworthy compared to the other conditions. Importantly, IPD was even more reduced in participants infected with Covid-19 or living in low-risk areas, while it was not affected by the predicted health of the characters. These findings shed further light on the psychological factors that motivate IPD adjustments, in particular when facing a collective threat. They are also of crucial importance for policy makers as they reveal that despite the indisputable value of wearing a face mask in the current pandemic context, their use should be accompanied by an emphasis on social distancing to prevent detrimental health consequences.

Keywords: social interaction; COVID-19; interpersonal distance; face mask; facial expression

Introduction

The Covid-19 pandemic began in China in December 2019 and quickly spread around the world, with 3 889 841 cases reported in 187 countries as of May 8, 2020 (Covid-19 interactive dashboard, Dong, Du, & Gardner, 2020). To slow down the pandemic, it is critical to ensure that human behavior with respect to preventing infection is represented appropriately. In accordance with WHO guidelines, many governments recommended the use of barrier gestures in social contexts such as regular hand-washing, maintaining an inter-individual distance of at least 1 meter, and wearing a medical mask (World Health Organization, 2020). Although highly encouraged due to its obvious sanitary impact, the wearing of a face mask has social consequences that have not yet been studied in depth, and its interaction with other barrier gestures such as social distancing is unknown.

Indeed, since the pioneering work of Hall (1966) and Hediger (1968), social interactions are known to require a fine adjustment of interpersonal distances (IPDs). Selecting an appropriate IPD involves two constraints: the need to approach conspecifics given the interaction's physical constraints and the need to maintain a margin of safety to protect the body from potential hazards (Dosey & Meisels, 1969; Hayduk, 1983; Siegman & Feldstein, 2014). IPDs are thus not consistent across social situations, but are modulated by physical, cognitive and affective factors (Coello & Iachini, 2015). For instance, increasing the dimensions of conscious body representation using tools (Canzoneri et al., 2013) produces IPD extension (Quesque et al., 2017). Likewise, IPD increases when facing conspecifics with angry compared to happy or neutral facial expressions (Cartaud et al., 2020, 2018; Ruggiero et al., 2017), and is also atypical in people with socio-emotional deficits (Givon-Benjio & Okon-Singer, 2020; Kennedy et al., 2009; Nandrino et al., 2017). Importantly, interacting with people wearing a face mask might alter in the first place the affective dimension of social interactions (Beaudry, Roy-Charland, Perron, Cormier, & Tapp, 2014; Eisenbarth & Alpers, 2011; Schurgin et al., 2014).

Given the social context associated with Covid-19, it is essential to understand how IPD, a determining factor in blocking contamination, would be influenced by barrier gestures such as wearing a face mask, especially in view of the current and general deconfinement of populations around the world. The effects on IPD might be even harder to anticipate as quarantine periods generally lead to massive behavioral and emotional changes (Brooks et al., 2020). This is a critical issue, as a potential negative effect could be that wearing a face mask significantly enhances the feeling of safety despite the pandemic context and could jeopardize other health recommendations such as social distancing. Through a massive internet-based experimental study, we investigated this issue by asking participants to estimate whether the distance at which virtual characters were presented was appropriate or not for interacting with them. The virtual characters either wore a face mask, or wore no mask but displayed a happy, angry or neutral facial expression. The use of emotional expressions provides a well-established referential to investigate the (positive-negative) emotional effect of the face mask on IPD (Cartaud et al., 2018; 2020; Ruggiero et al., 2017). Indeed, if the presence of a face mask induces a negative feeling and is interpreted as a "threatening" cue, in particular in the current pandemic context, one should expect the IPD to increase as this is observed with characters displaying a negative emotion (angry), in comparison to the neutral condition. On the contrary, if the presence of a face mask induces a positive feeling and is interpreted as a "protective" cue, one should expect the IPD to decrease in comparison to the neutral condition, as this is the case for characters displaying a positive emotion (happy).

Method

Participants

Four hundred and fifty-seven adult volunteers (323 women) completed the entire experiment (*M*age = 31.53, *SD*age = 13.37). The sample size was not determined a priori as the authors expected to include as many participants as possible before the end of the Covid-19 quarantine period in France. However, the sample obtained largely exceeds the minimal sample size (n=50) required to reasonably observe an effect characterized by a relatively small effect size (Cohen's d =0.4) and a standard power criterion (0.8). Written informed consent was obtained from each participant and the protocol received approval by the local institutional ethics committee (CESC Lille, Ref. 2020-425-S83).

Apparatus and stimuli

The experiment was created on lab.js builder (Henninger et al., 2019), run online, and hosted on the CNRS web server. Advertisement was shared on social and professional networks. The stimuli consisted of eight male and female virtual characters selected from the ATHOS database (all stimuli are available at: https://osf.io/sp938/?view_only=7a5c397f51864d88a7f71af2c18bf478). A total of 4 male and 4 female characters were used in the present experiment. They were presented in an empty room with an angry, happy or neutral facial expression, or with a white face mask. When the virtual character had a face mask, the facial emotion was neutral so as to avoid confounding factors (Carbon, 2020). Both the characters and the empty room were built on Unity (2018.2.21f1 version). The facial expressions (FE) were randomly assigned to the characters providing thus for each participant a specific set of 4 characters with 4 FEs for each gender. The characters were presented at different distances along the virtual mid-body sagittal axis of the participants. Distances varied from 28 to 140 cm with respect to the proximal side of the virtual room (see

Fig. 36 for an illustration). The distance increment was 8 cm, resulting in 15 possible distances. Variables were manipulated with a within-subject design and the order of the 240 stimuli presented was fully randomized (Gender of the virtual character [2] * FE [4] * Distance [15] * Repetition [2]).

Procedure and design

After having completed a short questionnaire concerning general information (the full questionnaire is available in supplementary material), participants had to perform two tasks. The first task was to judge whether the IPD between themselves and a virtual character was appropriate for social interaction or not. The characters (female and male) were presented one by one, standing motionless at a distance ranging from 28 to 140 cm from the proximal side of the virtual room, and with different FEs (anger, happy, neutral, face mask). Each virtual character was presented twice. Responses were provided by pressing the “L” (appropriate) or “S” (inappropriate) keyboard keys (which are separated apart symmetrically on “Azerty” keyboard). Participants were instructed to respond spontaneously and as fast as possible. A 10-trial training session on independent virtual characters (not used in the following task) was administered before the experimental session to operationalize the associations between responses and keys. After 120 trials, a break was proposed to participants, if needed. The second task consisted in explicit judgements of the characters’ attributes. Participants were presented sequentially with the characters used in the first task. They were displayed at a fixed distance, 61 cm away, and several questions appeared below. The characters, presented in random order, were evaluated on whether they were “threatening”, “determined” and “trustworthy” (Cuddy, Fiske, & Glick, 2008) and also “healthy” due to the obvious interest given the present health context. Responses were provided by positioning a cursor on a horizontal line (100 units) with the label "really agree" on the right side and "really disagree" on the left side. Participants used their trackpad or mouse to position the cursor.

Data analysis

The data were collected the last two weeks before the end of the French quarantine period (two weeks before 11th of May 2020). Statistical analyses were carried out using generalized linear model regression (GLM) and linear models, with R (version 3.5.1) and R Studio software (version 1.1.463), for IPD and characters' attributes respectively. Post-hoc comparisons were carried out using Bonferroni correction for the logistic regression and Tukey HSD test for the linear models (lsmeans package, version 2.30-0). The probability of "appropriate" responses was analyzed using GLM (logistic regression) as a function of the Distance (28 cm to 140 cm), FE of virtual characters' (angry, happy, neutral, face mask), Covid-19 contamination (yes, no), Virtual characters' gender (male, female), and Area risk level (low, high), according to the model:

$$\begin{aligned} Response \sim\ & Distance + FE + Covid19\ contamination \\ & + Area\ risk\ level + Virtual\ character\ gender \\ & + FE \times Covid19\ contamination \\ & + FE \times Virtual\ character\ gender \\ & + FE \times Area\ risk\ level \end{aligned} \tag{26}$$

Then, the boundary of appropriate IPD for each condition was determined from the participants' responses at the different distances using the equation:

$$y = \frac{e^{(\alpha + \beta X)}}{1 + e^{(\alpha + \beta X)}} \tag{27}$$

in which y is the participants' response (appropriate/inappropriate), X is the distance, and $-\alpha/\beta$ (logistic parameters) is the critical value of X corresponding to the transition between appropriate and inappropriate responses, thus expressing the preferred IPD. Thus, given that the boundaries of appropriate IPD are computed from the same response as the coefficients reported in Table 5, if the odds between two conditions is not statistically significant, then neither is the difference between the boundaries of appropriate distance in these two conditions.

The participants' subjective evaluation of the characters' attributes (threat, health, trust and determination) were analyzed as a function of the characters' FE (angry, happy, neutral, face mask), participants' Covid-19 contamination (yes, no) and risk level of geographical area (low, high). Data and statistical analysis are available on the OSF platform (https://osf.io/utb4c/?view_only=53520fa0db42449e8595b49fba878b55).

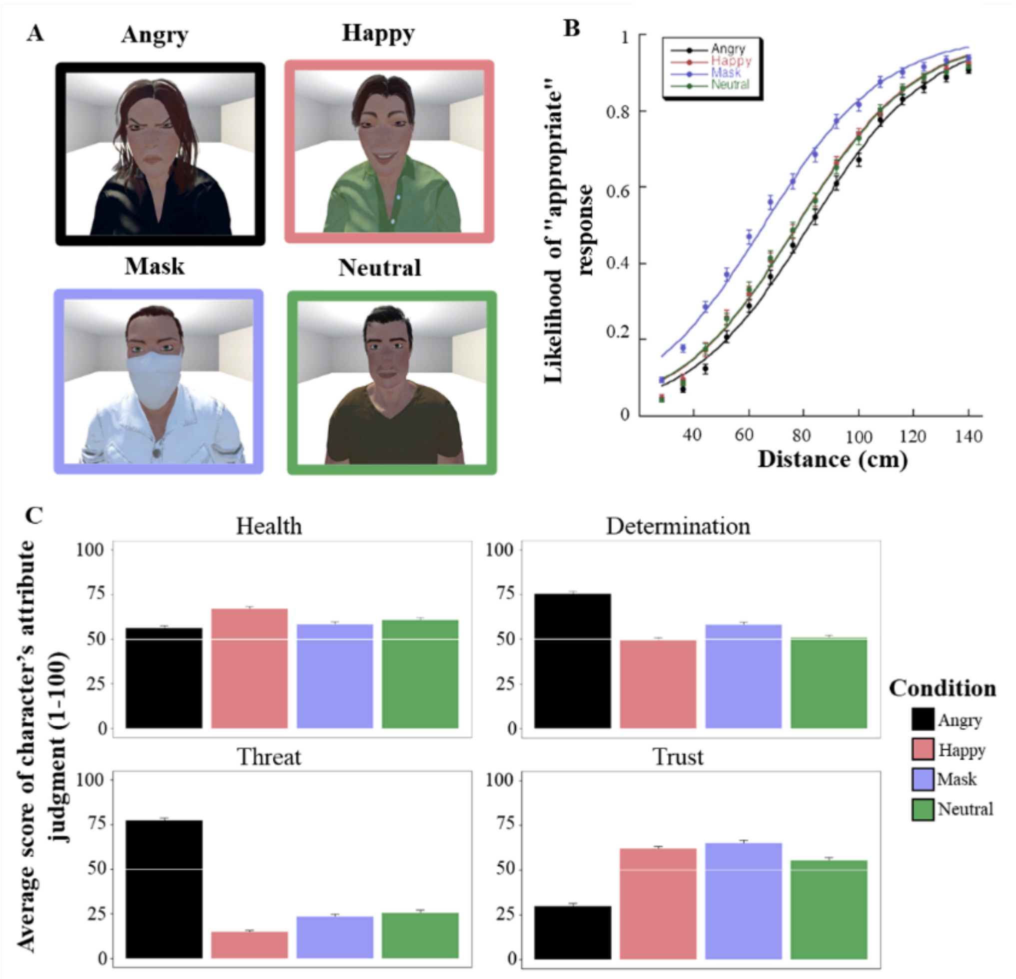

Fig. 36. **Stimuli used in experiment and graphical representations of IPD and attributes judgments** (A). Examples of the characters used in the experiment (shown at a distance of 36 cm). (B) Logistic regressions relating to the likelihood of "appropriate" responses as a function of the distance according to the characters' facial expression (Angry, Happy, Mask, Neutral). (C) Mean score of characters' attribute judgement (Trustworthy, Threatening, Healthy, Determined) as a function of the characters' facial expression (Angry, Happy, Mask, Neutral) and 95% Confidence Interval.

Results

Out of the 457 participants living in 55 different French departments, 51 declared being or having been contaminated by Covid-19 and 341 lived in a high-risk area (according to the French government's classification). When testing how participants judged IPD, the results showed that the appropriate distance was on average 76.6 cm (Fig. 36B), but that it depended on the character's FE (Table 1, statistics are expressed in odds ratio). The preferred IPD was much shorter for the character with a face mask (66.41 cm) than when he/she had a neutral (78.50 cm) FE. Interestingly, it was also shorter when compared to the characters with a happy (78.21 cm) or angry (83.1 cm) FE (all $p<0.01$). However, characters with a neutral FE had a shorter preferred IPD than characters with an angry FE ($p<0.01$), but not different from those with a happy FE ($p>.10$). Overall, these distances were modulated by individual factors. On average, preferred IPD was shorter when facing a female (75.38 cm) than male characters (77.82 cm, $p < 0.001$). It was also shorter when participants had been contaminated with the Covid-19 (3.2 cm, $p<0.01$) or when they lived in a low-risk area (3.79 cm, $p <0.01$). However, no interaction with the FE emerged.

Regarding the character's attributes (Fig. 36.C), a main effect of FE emerged for threat ($F= 1453.46$, $p < 0.001$), health ($F =41.24$, $p <0.001$), trust ($F =404.68$, $p < 0.001$) and determination ($F = 277.36$, $p <0.01$) evaluations. The characters with a face mask were evaluated as slightly more threatening (Mthreat = 23.33, CI = ± 1.51) than those with a happy FE (Mthreat = 14.63, CI = ± 1.27, $p <0.001$), but less than those with an angry FE (Mthreat 77.26, CI = ± 1.49, $p<0.001$), and not different from those with a neutral FE (Mthreat = 25.60, CI = ± 1.57, $p = 0.14$). They were also evaluated as less healthy (Mhealth = 58.31, CI = ± 1.32) than those with a happy FE (Mhealth = 66.82, CI = ± 1.41. , $p<0.001$), but not different from those with an angry (Mhealth =56.35, CI = ± 1.40, $p = 0.20$) or a neutral FE (Mhealth = 60.83, CI = ± 1.41,$p = 0.058$). The latter were significantly different from each other ($p <0.01$). They were rated as more trustworthy (Mtrust = 65.1, CI = ± 1.48) than the characters with an angry FE (Mtrust = 29.73, CI = ± 1.6, p<0.01), neutral FE (Mtrust = 55.38, CI = ± 1.51, p < 0.001) or happy FE (Mtrust = 61.78, CI = ± 1.66, p = 0.02). Furthermore, they were evaluated as being more determined (Mdetermined =58.16, CI = ± 1.38) than characters with a happy (Mdetermined = 49.28, CI = ± 1.46, p < 0.001) or neutral FE (Mdetermined = 50.79, CI = ± 1.49, p < 0.001), but less than those with an angry FE (Mdetermined = 75.54, CI = ± 1.34, p < 0.001). Finally, the evaluation of threat (F= 6;24, p = 0.01) and trust (F = 6.69, p <0.01) were dependent on the area risk level. Individuals living in a low-risk area rated the characters as less threatening (Mthreat = 33.6, CI = ± 2.15) than those living in a high-risk area (Mthreat = 35.76, CI = ± 1.25, p = 0.01). They also evaluated the characters as more trustworthy (Mtrust = 54.77, CI = ± 1.77) than individuals living in a high-risk area (M=trust = 52.4, CI = ± 1.05, p = 0.01).

Table 5. Coefficients of the logistic regressions for the different variables. Odds ratios represent odds of answering “appropriate” when exposed to a Condition compared to answering “appropriate” when exposed to the Reference.

Reference	**Estimate**	**Coefficient**	**Standard Error**	**z value**	**p**	**Odd ratio**
Face Mask	Neutral	-0.544	0.022	-25.106	<0.001	0.581
	Angry	-0.754	0.022	-34.712	<0.001	0.47
	Happy	-0.529	0.022	-24.433	<0.001	0.589
Neutral	Happy	0.015	0.021	0.684	ns	1.015
	Angry	-0.211	0.021	-9.85	<0.001	0.81
Happy	Angry	-0.225	0.021	-10.532	<0.001	0.798
No Covid-19	Covid-19	0.128	0.024	5.285	<0.001	1.136
Risk-related high	Risk-related low	0.185	0.017	10.545	<0.001	1.203
Female characters	Male characters	-0.114	0.015	-7.532	<0.001	0.892

Discussion

The Covid-19 pandemic represents a massive global health crisis with an unprecedented social and behavioral impact. The consistent message conveyed by health stakeholders is that the struggle against it requires significant behavioral changes. In the present study, we investigated to what extent barrier gestures interact, and in particular how wearing a face mask impacts social distancing, an essential measure against Covid-19 transmission. By using an original online paradigm in a lockdown context, our aim was to evaluate the (positive-negative) emotional valence carried by the face mask through its effect on IPD, and to compare this effect to that associated with emotional facial expressions (Cartaud et al., 2018; 2020; Ruggiero et al., 2017). We observed a significant decrease in preferred IPD when the social interaction involved a character wearing a face mask in comparison to a character with no face mask but displaying a happy, angry, or a neutral facial expression. In addition to this first result, we found that an area's risk level regarding Covid-19 contamination affected preferred IPD. The lesser the expected risk in a particular area, the less social distancing seemed paramount to individuals. Moreover, a similar effect held for individuals contaminated with Covid-19, who felt that shorter IPDs were appropriate. One interpretation could be that being already affected by Covid-19, they might not experience the strict need to adopt barrier measures to protect themselves. Another interpretation could be that because they were more prone to select a shorter distance, they were concurrently more exposed to Covid-19 contamination. Further experiments will be needed to disentangle these two interpretations. In any case, the present findings call for high vigilance regarding social distancing policies. They deserve particular attention in the present context as threatening circumstances classically lead people to seek social interactions and physical contacts (El Zein, Bahrami, & Hertwig, 2019; Mawson, 2017; Morrison, 2016). Furthermore, since wearing a face mask cannot be considered as a sufficient safety barrier gesture in itself (Hui et al., 2012; but see also Worby & Chang, 2020), these findings highlight the need to foster vigilance regarding individual practices, especially in "low-risk" areas.

Concerning subjective evaluations of the characters, those displaying an angry facial expression were rated as more threatening than the others. Interestingly, characters with happy facial expressions were evaluated as less threatening than those wearing a face mask, despite the fact that we observed smaller IPD when interacting with the latter. At first sight, these results might be surprising regarding previous findings on spatial adjustment to threatening stimuli (Cartaud et al., 2018; 2020; Ruggiero et al., 2017). However, masked, neutral and happy characters were all associated with very limited levels of threat. Moreover, the characters wearing a face mask were evaluated as more trustworthy than the others. This could have led to the reduced IPD observed with masked characters (Fini et al., 2020; Iachini, Pagliaro, et al., 2015), in relation to the positive feeling triggered by the mask, and also because "morality" judgments (as opposed to "competence" judgements) represent the core determinant of approach–avoidance tendencies toward conspecifics (Fiske et al., 2007). Therefore, perceived determination was unrelated to the regulation of IPD, as a proxy of the competence dimension. Finally, characters with a face mask were evaluated as less healthy than those with a happy facial expression, but no different from the characters with an angry or neutral facial expression. Overall, health judgements were relatively high for all characters, and were not related to the regulation of IPD. Consequently, distancing behavior based on simple visual markers might thus not operate in the current Covid-19 context as it is a largely "invisible" disease that remains asymptomatic in a large part of the population (Dezecache, Frith, & Deroy, 2020).

Critically, the present study also replicates classical findings. Specifically, we observed an increase in IPD in the presence of angry facial expressions in comparison to neutral or happy facial expressions (Cartaud et al., 2018; 2020; Ruggiero et al., 2017). In the same vein, smaller IPD were judged appropriate when interacting with female rather than male virtual characters

(Cartaud et al., 2020; Iachini et al., 2016). Altogether, the fact that classical effects such as the influence of the gender of the stimuli and valence of facial expressions were replicated here, underlines the good external validity of our stimuli and paradigm.

It is noteworthy that the present study aimed at quantifying the impact of emotional valence associated with face mask on social distancing in a pandemic context. This was allowed by the comparison of estimated IPD for characters wearing a face mask with conditions classically investigated (i.e., emotional faces, Cartaud et al., 2018; 2020; Ruggiero et al., 2017). On purpose, our experimental design did not allow us to investigate the interaction between displayed emotion and the presence of a face mask as this question did not represent a critical sanitary issue. This may represent a limit of the present study. This and other specific issues will need to be addressed in future work, taking into account that a recent study demonstrated that emotional identification is strongly impaired by the presence of a face mask (Carbon, 2020).

Recent works (Van Bavel et al., 2020) highlighted the difficulty of making public policy and government decisions based solely on rationalization, as multiple cognitive biases stand in the way of risk prevention in social contexts. Among these biases leading to maladjustment of social behaviors, people generally underestimate health-related risks, find it unnatural to respect strict isolation as a means of protecting others, and have only a limited awareness of the actions that pose a health risk. Although the present study calls for generalization in more ecological settings, it provides further evidence of these biases by showing that the mere sight of a person wearing a face mask is enough to trigger a strong feeling of safety that acts against the simplest rule of social distancing. Accordingly, general recommendations to wear a face mask in society as an efficient barrier gesture against Covid-19 must be accompanied by a strong incentive to respect social distancing.

Supplementary material: Questionnaire

- Age
- Gender (Male/Female/Other)
- Height
- Weight
- Region of residence
- At the present time, do you feel anxious (continuous scale: Not at all - extremely)
- At the present time, do you feel depressed (continuous scale: Not at all - extremely)
- What is your current situation: working at your workplace/ working from home/ furloughed/ volunteer (related to Covid-19)
- Will the quarantine have consequences on your professional activity in the future (None/ small/ significant/ very great)
- Are you currently using public transport (every day/ several times a week/ once a week/ once or twice a month/ never)
- Are you or have you been contaminated by Covid-19 (Yes, I was/ I am presently/There has been no diagnosis, but I think so/ There has been no diagnosis, but I do not think so/ No)
- Do you have any relative who is or has been contaminated by Covid-19 (Yes, I was/ I am presently/There has been no diagnosis, but I think so/ There has been no diagnosis, but I do not think so/ No)
- Are you presently in quarantine (yes/ no/ no but I was)
- Date your quarantine began
- Date your quarantine ended (if applicable)
- During the period of quarantine, have there been any significant changes in your interactions with others (yes/no)
    - Changes in frequency (increase in the number of interactions/ decrease/ no change)
    - Changes in the number of people (increase/ decrease/ no change)
    - Changes in intensity (I feel closer to the people I am interacting with/ I feel farther away/ no change)
- To what extent has the quarantine changed your daily organization (continuous scale: Not at all - extremely)
- To what extent are you worried about your health (continuous scale: Not at all - extremely)
- To what extent are you worried about the health of your relatives (continuous scale: Not at all - extremely)
- Do you wear a face mask (all day long/ every day, for a few hours/ several times a week/ less than once a week/ never)
- Do your relatives wear a face mask (all day long/ every day, for a few hours/ several times a week/ less than once a week/ never)
- How often do you get the latest news on Covid-19 (continuously/ several times a day/ once a day/ several times a week/ less than once a week)
- How do you get the latest news on Covid-19 (news site on the internet/ social network/ TV/ Radio/ Written press)
- Do you trust the media regarding news about Covid-19 (not at all/ rather not/ indifferent/ rather yes/ absolutely)
- Do you trust French politicians regarding Covid-19 (not at all/ rather not/ indifferent/ rather yes/ absolutely)
- Do you trust scientists and researchers regarding Covid-19 (not at all/ rather not/ indifferent/ rather yes/ absolutely)

GENERAL DISCUSSION

I. OVERALL SUMMARY

Evidence suggests that the brain represents the space as a series of subspaces rather than as a continuum. This space division depends on our ability to physically interact with the objects that compose our environment (Previc, 1998; Rizzolatti et al., 1997). Among these spaces lies the PPS which can be seen as an abstract multisensory interface between the body and the objects at hand (Serino, 2019). PPS is thus a space in which we can interact *hic et nunc* with the elements of the environment and its representation relies on both motor actions and defense mechanisms related to the valence of objects (Coello et al., 2012; Graziano, 2017; Serino, 2019).

IPD adjustment is of paramount importance as it contributes to optimal interaction: a too large distance is not conducive to social interaction whereas a too short distance triggers discomfort (Hall, 1969; Hayduk, 1978; Lloyd, 2009). The distance between two individuals during social interaction (IPD) seems to rely specifically on sensorimotor representations similar to those of the PPS (Quesque et al., 2017; Vieira et al., 2019). Multiple social factors contribute also to IPD adjustment and in particular personal and others' emotional state (Iachini, Ruggiero, et al., 2015; Ruggiero et al., 2017). Emotional states can be easily identified through FE of emotion (Darwin, 1872; Ekman, 1999). Indeed, FE are automatically produced and can be very informative regarding the behavioral intentions of others, which can, as a consequence, inform us about the potential threat the individual can be in regards to our physical integrity (Darwin, 1872; Waller et al., 2017). As such, IPD decreases with individuals displaying a happy FE, whereas it increases with individuals displaying an angry FE (Ruggiero et al., 2017; Vieira et al., 2019).

The emotional (positive-negative) valence of a stimulus, do not only rely on its intrinsic value but may also depend on the emotional context in which the stimulus is presented (Manis, 1967; Matsumoto & Sung Hwang, 2010; Wedell & Parducci, 1988; Wieser & Brosch, 2012).

For example, a negative stimulus will be perceived as more negative if embedded in a negative context (Halberstadt & Niedenthal, 2001; Parkinson, 2019).

The effect of the context is not always straightforward. Indeed, when neutral stimuli are embedded in a negative context, they are sometimes judged as being more negative than they are (Corbin & Crawford, 2018; De Houwer et al., 2001) and sometimes as being less negative than they are (Furl, 2016; Wedell & Parducci, 1988). Both pattern of results can be related to the assimilation effect and the contrast effect respectively. As detailed in section II.2.3. of the Introduction, assimilation and contrast effects depend on the type of context influence (spatial or temporal contiguity between the context and the target stimulus) and on the range and the frequency of contextual stimuli (Martin et al., 1990; Matsumoto & Sung Hwang, 2010).

In addition to behavioral and evaluative responses, FE perception also triggers specific physiological and cerebral reactions (Adolphs, 2002b; Kret et al., 2013). These reactions are automatically triggered by emotional situations and prepare the body to react (Scherer, 2005). When perceiving a potential threat (e.g., an angry FE), multiple cerebral structures (at both the cortical and subcortical level) are activated, they quickly interact with one another to rapidly trigger the most appropriate body adjustments, leading to motor preparation, and approach-avoidance strategies (Adolphs, 2002b; LeDoux, 1998). The electrodermal response is one of the physiological markers of defense mechanisms. Indeed, EDA reflects the level of physiological arousal as it is related to the activity of the sympathetic nervous system which is mainly associated with "fight and flight" tendency (Boucsein, 2012; Jänig, 2006). The physiological and cerebral responses increase both with the increased intensity of the threat (Boucsein, 2012; Foster & Harrison, 2002; Jänig, 2006), and with the increased proximity of the threat (Kennedy et al., 2009; Lloyd, 2009; Vieira et al., 2019; Wilcox et al., 2006).

In this context, the aim of the present thesis was twofold:

- To investigate the extent to which IPD is built on PPS and to what extent it depends on the emotional valence of individuals
- To investigate the extent to which the emotional context determines the perceived valence of individuals and thus contribute to IPD adjustment

In order to investigate the first issue, we conducted two studies (Study 1 and Study 2). In Study 1, participants' EDA was recorded while PLD with an angry, happy or neutral FE was presented either in their PPS or in their extrapersonal space during a reachability judgment task. After this first task, participants performed an IPD judgment task during which the same PLD approached and crossed participants at different inter-shoulder distances. First, we observed an increase in EDA when PLD with an angry FE were displayed within the PPS. Second, we found that the preferred IPD was larger with PLD with an angry FE than with PLD with a happy or neutral FE. Third, when considering PLD with an angry and a neutral FE, we observed a linear relation between EDA to stimuli within the PPS and the preferred IPD with the same stimuli. Overall, this study revealed that the intensity of the physiological response to threatening social stimuli within the PPS expresses the defensive dimension of PPS. This defensive response to threat can be coded in terms of distances so as to contribute to the specification of IPD.

Study 2 was designed to assess the robustness of the effects observed in Study 1. More precisely, we investigated whether the physiological and IPD changes observed in Study 1 would remain unchanged when emotional FE are presented very briefly, just before the appearance of the neutral PLD. Our rational was that it may represent a more ecological situation since, in our everyday life, we can only perceive others surreptitiously, with no in-depth treatment of their FE. Concurrently, Study 2 allowed us to investigate whether the emotional information conveyed by the FE would spread to the neutral PLD (assimilation effect). First, participants performed a task during which they categorized the FE, displayed only 16 ms with various levels of luminance in order to establish an individual perceptual threshold. Then, they performed an IPD judgment task. In the first session, participants' EDA was recorded while neutral PLD crossed participants at three inter-shoulder distances (closer, equal to or larger than the average IPD established in Study 1). The PLD was preceded by an angry, happy or neutral FE presented at the individual perceptual threshold of each participant. The second session was used to establish the preferred IPD. First, we observed that participants' EDA was higher when they were exposed to an angry FE than when they were exposed to a neutral FE, but only when the PLD violated their preferred IPD. Second, we found an increase in IPD when the PLD was associated with an angry FE and a decrease in IPD when the PLD was associated with a happy FE, when respectively compared to the situation in which the PLD was associated with a neutral FE. However, no clear relation emerged between the physiological response to stimuli violating preferred IPD and preferred IPD. This study revealed that exposure to an emotional FE at the perceptual threshold is sufficient to produce both a physiological response and an IPD adjustment, even when interacting with a neutral social stimulus.

Study 3 aimed at investigating the effect of the emotional context on the valence-dependent IPD adjustment. More precisely, we investigated whether the contrast effect observed on valence judgment could alter IPD adjustment. In Study 1 and 2, the emotional information (FE) was associated with a neutral PLD (leading to assimilation effect). Therefore, in Study 3, we disentangled the emotional information from the neutral characters by designing an emotional context composed of virtual characters displaying either an angry or happy FE. We investigated whether this emotional context altered the valence judgment as well as the preferred IPD with characters embedded in the context and displaying a neutral FE. First, we presented singly emotional (angry or happy) and neutral characters to participants who judged those characters in terms of valence. Next, participants performed an IPD judgment task with the same characters. In a second session, participants performed the same task but with the other emotional (happy or angry) characters and a new set of neutral characters. Classical contrast effect was observed for valence rating: neutral characters embedded in a negative context were judged more positively than neutral characters embedded in a positive context. However, the emotional context only mildly altered IPD judgments. IPD with the neutral characters from the negative context did not differ from IPD with the neutral characters from the positive context. Nonetheless IPD with the neutral characters of each emotional context differed from IPD with the emotional characters constituting their context, but not from the other emotional context (e.g., the IPD related to neutral characters embedded in the negative context were shorter than the IPD related to angry characters, although it was not different from the IPD related to happy characters). This study suggests that, although the emotional context influences valence judgments of neutral stimuli, it has only a weak effect on IPD adjustment which seems to rely primarily on categorical information of the emotional FE.

Finally, Study 4 was carried out at the end of the Covid-19 lockdown which was an opportunity to test emotion effect on IPD in an ecological context. We investigated how IPD could be altered by the use of a face mask. A face mask does not convey any information about others' emotional state *per se*. Instead, the information it conveys can be considered as ambiguous. A face mask can be seen either as a threatening stimulus, a reminder of the pandemic situation or as a positive stimulus, a protection against the Covid-19. During this online experiment, participants performed an IPD judgment task with virtual characters presented at different distances with different FE (anger, happy, neutral, face mask). Then, they rated them in terms of threat, determination, trust and health. The IPD associated with the angry characters were the largest one, compared to any other characters. Surprisingly, the IPD with characters wearing a face mask were shorter than IPD with angry, neutral and even happy characters. Masked characters were also judged as more trustworthy than all other characters.

This study suggests that wearing a face mask during a pandemic context induces a strong feeling of safety leading to a reduction of IPD. It also suggests that external information about others can participate to IPD adjustment, as can more intrinsic information such as the one related to emotional state.

II. BINDING OF PPS AND VALENCE INFORMATION IN IPD SPECIFICATION

Throughout this thesis, we highlighted how PPS and valence information contribute to IPD adjustment. In particular, we measured how the perceived level of threat (through physiological activity) within the PPS affected IPD adjustment. As the PPS is a multisensory interface between individuals and their environment, relying in part on defensive mechanisms (Graziano, 2017; Serino, 2019), stronger defensive responses are observed to increased threat within PPS (Graziano & Cooke, 2006; Rossetti et al., 2015; Vieira et al., 2019). As IPD is built on PPS (Quesque et al., 2017; Vieira et al., 2019), IPD also depends on defensive mechanisms underlying the PPS representation. We propose that IPD is determined by these defensive responses within the PPS. The present thesis brings new contribution to the growing theoretical framework regarding the relation between PPS and IPD. Indeed, while some authors have argued in favor of a dissociation between PPS representation and IPD due to opposite effects of the same variables (D'Angelo, di Pellegrino, & Frassinetti, 2017; Patané et al., 2017, 2016), others argued in favor of a similar representation (Iachini et al., 2016; Iachini, Pagliaro, et al., 2015; Ruggiero et al., 2017). Our data supports that PPS contributes to defining IPD, in relation to its intrinsic protective value (no one is allowed to invade others' PPS without being explicitly invited to do so), but that IPD contains also an extra margin that adapts depending (in particular) on perceived valence in others (Serino, 2019). As a result, IPD relies on a spatialization of homeostasis, related to physiological responses triggered by individuals within the PPS because of its underlying defensive mechanisms.

This relation between defensive responses within the PPS and the adjustment of IPD seems to follow a linear relationship (see the function below): the stronger the response in PPS, the larger extent of IPD, which is in line with approach-avoidance behaviors. This positive relation between PPS and IPD is relatively consistent with the literature since defensive responses increase with the proximity of threatening individuals (Ellena et al., 2020; Kennedy et al., 2009; Vieira et al., 2019). Even in animals, behavioral tolerance (not fleeing when a human is close) is associated with a physiological cost (longer duration of high physiological response, Charuvi et al., 2020). Therefore, if we refer to the assumption that IPD relies on homeostasis, it is legitimate to keep threatening individuals who, at a given distance, trigger stronger physiological response, further away than seemingly harmless individuals. We suggest that IPD is derived from the level of threat perceived within the PPS (more developed in the next section).

Furthermore, the mechanisms inducing IPD adjustment seem to be fast and low level as they do not require an extensive treatment of the emotional information. Indeed, IPD adjustment is observed even when emotional stimuli are presented at the perceptual threshold. So far, we knew that the perception (from subliminal to supraliminal) of emotional FE induced cerebral and physiological responses (Adolphs, 2002a; LeDoux, 1998; Öhman & Soares, 1994) and that their recognition can be fast (Palermo & Rhodes, 2007; Vuilleumier, 2002). Since IPD depends both on physiological responses and the emotional valence of social stimuli, it makes sense that emotional FE, even if only surreptitiously perceived, alter IPD adjustment. Therefore, IPD adjustment is a rapid, adaptive reaction. IPD adjustment depends on threat perception in relation to PPS which does not require a deep treatment of emotional FE of others.

Another original point regarding the outcome of this thesis is related to the effect of emotional information from the context on IPD adjustment. IPD adjustment can be in the approach or avoidance direction as it depends on the valence of others. Positive FE trigger approach behaviors whereas negative FE trigger avoidance behaviors (Lockard et al., 1977; Ruggiero et al., 2017; Vieira et al., 2019). However, the emotional context can also impact the judgment of the emotional valence of FE (Matsumoto & Sung Hwang, 2010; Russell & Fehr, 1987; Wedell & Parducci, 1988; Wieser & Brosch, 2012). The present thesis sheds new lights on the effect of perceived valence, depending on the emotional context, on IPD judgments. Indeed, contrast effect, which refers to a negative correlation between the valence of the emotional context and that of the social stimulus (Schwarz & Bless, 2007), only mildly altered IPD adjustment. Contrast effects are supported by theories based on mathematical models such as the RF theory (Parducci, 1965) or the DN model (Louie et al., 2011). Accordingly, strong theoretical hypotheses can be made and quantitative predictions can be drawn. However, we found that valence (as a continuous dimension) had only little effect on IPD adjustment, which would mean that IPD adjustment is not really influenced by the emotional context. Therefore, within a specific emotional category (e.g., neutral FE), contrast effect on valence judgment do not apply to IPD. This observation could be interpreted as individuals rely more on categorical perception of emotional FE than on continuous variation of valence information (Fujimura, Matsuda, Katahira, Okada, & Okanoya, 2012). Valence evaluation could thus be better conceptualized in terms of bimodal assessment (e.g., rather positive vs rather negative) rather than dimensional assessment, without implying a specific gradation. Indeed, even when a dimensional perception of FE is available (judgments based on a continuous or discrete valence scale), individuals are more likely to categorize FE as “rather positive” or “rather happy” than “7/10 valence”. This categorization bias would be related to the prevalent role of language during the rating of FE (Fujimura et al., 2012). Therefore, it seems that FE category has more weight than its valence dimension, especially in terms of IPD adjustment. The subtle contrast effect observed in Study 3 on IPD adjustment is nevertheless supported by the RF theory since we observed a shift in IPD adjustment with neutral characters depending on the emotional context in which they were displayed (Parducci, 1965). Indeed, since extreme IPD (minimum or maximum, depending on the context) are quite close from each other, the mathematical formalization of RF theory predicts a weak contrast effect. Taking into account both the categorization bias of emotional FE and the weak contrast effect prediction, classical contrast could hardly be observed. Therefore, IPD adjustment seems only mildly sensitive to emotional information from the context, supporting the importance of emotional FE of the target individual on defensive behaviors (Darwin, 1872).

Furthermore, and in line with the categorization bias of emotional FE, contrast effect might not be able to compete with more basic approach-avoidance motivations (Elliot, 2008). Indeed, happy (angry) individuals trigger approach (avoidance) behaviors when compared to neutral individuals (Lockard et al., 1977; Ruggiero et al., 2017; Vieira et al., 2019). For example, neutral individuals but with positive valence may not still match with the “positive dimension” leading to approach behavior. This interpretation should however be investigated more thoroughly, using, for instance, emotional stimuli characterized by more intense valence (leading to stronger a contrast effect if relevant).

III. TOWARDS A NEW THEORETICAL APPROACH OF IPD ADJUSTMENT

Overall, the present thesis suggests that IPD is a necessary margin between individuals that ensures homeostasis during social interaction. From the data obtained in the present thesis, we suggest that IPD emerges from the combination of PPS representation and the emotional valence of the social stimulus. First, as the PPS is an area dedicated to interaction with the environment whose representation relies specifically on defensive mechanisms (Coello et al., 2012; Graziano, 2017; Serino, 2019), it can be seen as a no-go zone during social interaction. As a consequence, non-intimate social life occurs essentially in the extrapersonal space. Therefore, as PPS should be inviolable by others, its boundaries contribute to the construction of IPD in association with the emotional valence of the social stimuli. If PPS is violated, this triggers a strong discomfort and defensive responses (Kennedy et al., 2009; Vieira et al., 2019). Second, preferred IPD also varies as a function of the emotional valence (i.e., degree of threat) of the social stimuli. A broader negative valence corresponds to a larger IPD, with a relation that seems to be linear.

In this thesis, we used EDA to quantify the perception of social threat within the PPS. Indeed, we demonstrated that EDA, which reflects the level of physiological arousal, is related to the perceived threat in the PPS. Our data confirmed that the physiological reactivity within the PPS can be used as a proxy of perceived threat; the higher the perceived threat, the stronger the physiological response in the PPS, and as a consequence the broader IPD. Thus, our data validate that, in non-intimate social life, IPD shall not be shorter than the size of PPS, and extends as threat increases. The combination of PPS representation and emotional valence seems to follow a linear relation (see Fig. 37).

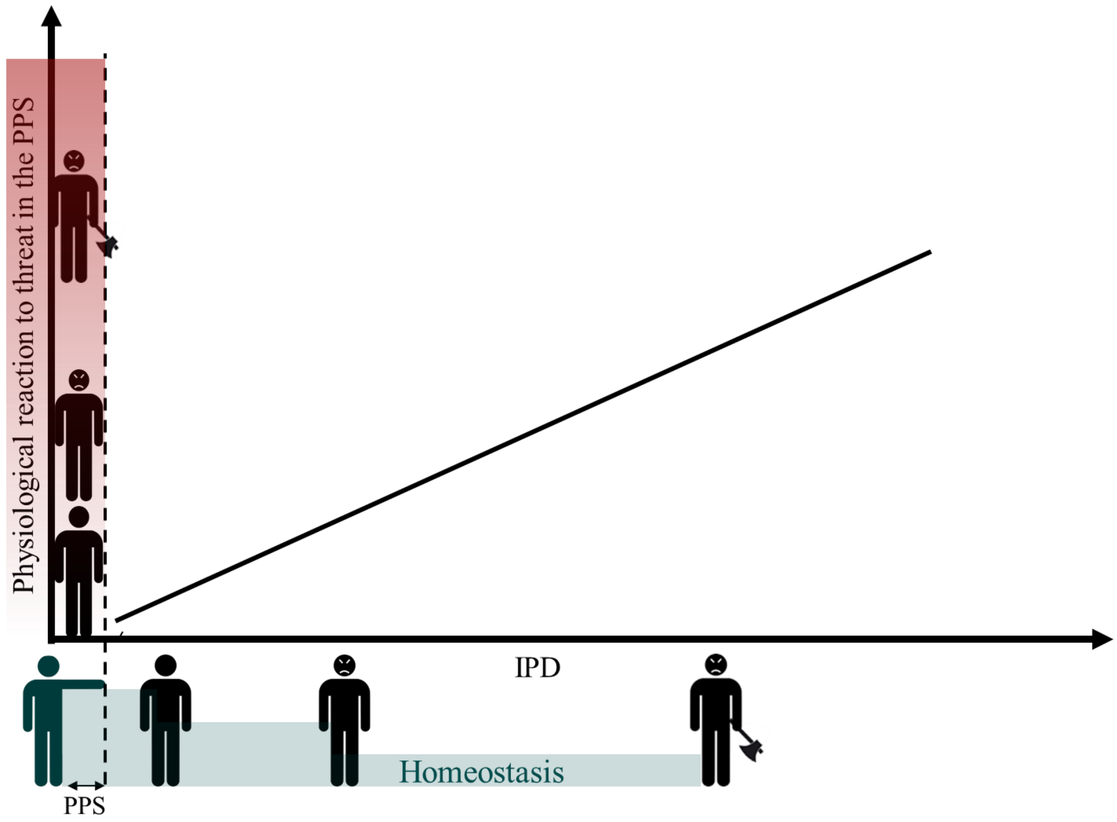

Fig. 37. Schematic representation of the function between the physiological response to threat within the PPS (y axis) and IPD (x axis). The degree of threat is schematized by: no face: neutral stimuli (no threat); angry face: moderate threat; angry face with an axe: high threat. The origin represents the position of the observer (in green). The dashed line represents the observer's PPS. The red banner represents the increasing physiological response. The green banners (bottom) represent the minimum IPD in order to maintain homeostasis. The axes of the graph are inverted in order to observe a horizontal representation of IPD. Not to scale.

IV. A FRAMEWORK FOR NEW RESEARCH AVENUES

IV.1. Valence intensity

The intensity of the effects observed in the present thesis may be underestimated because of the selected intensity of the valence of the emotional stimuli. Even if strongly contrasted, our stimuli might have not been threatening or positive enough to observe strong physiological differences or to significantly influence IPD. Using more intense stimuli could shed new lights both on the function between threat perception within the PPS and IPD adjustment and emotional context effect on the adjustment of IPD.

Regarding the effect of the emotional context, the contrast effect observed on valence judgment only mildly altered IPD adjustment. Based on this observation, we identified two main possible interpretations. Either IPD adjustment is mostly sensitive to categorical FE, therefore contextual information can only subtly alter them, or, the contribution of valence judgment on IPD adjustment is so subtle that stimuli with higher valence intensity are necessary to observe classical contrast effect. In order to disentangle these two hypothesis, it seems necessary to test the effect of emotional context on IPD adjustment with more intense emotional stimuli (Martin et al., 1990; Parducci, 1965). If an emotional context with higher intensity is still not sufficient to observe classical contrast effect on IPD adjustment (difference between IPD with neutral characters embedded in a positive and negative context), it would confirm the superiority of emotional FE category on the fine tuning of defensive responses (Darwin, 1872).

If no contrast effect is observed, it would indeed suggest that emotional information intrinsic to others are hardly altered by external features when it comes to adapt safety behavior, at least when the emotional information of the context and the one of the target individual are incongruent (non-informative context). Moreover, this would suggest that the effect of valence within the same category of emotional facial expression (e.g., very happy vs. mildly happy) has little effect on IPD adjustment, as if IPD adjustment was rather discrete (e.g., every threatening individual should be maintained at least at a specific minimum distance). If so, we can then refer to some extent to the principles of economics of flying from predators in animals (Ydenberg & Dill, 1986). According to Ydenberg and Dill (1986), risk of death in animals (thus flight distance) should increase with distance from cover, approach velocity and the size of the predator. Therefore, flight distance should remain the same if keeping these factors (and personal factors) constant. Further investigations are however required before considering the generalization of these principles to human social interactions. Note that it would explain why valence counts as a categorical variable on IPD adjustment but not as a continuous one.

Context with higher emotional intensity would thus be worth studying to assess classical contrast effect on IPD adjustment. Previous research revealed that the tendency to avoid negative individuals increased with the intensity of their emotional FE (Mennella, Vilarem, & Grèzes, 2020; Vilarem, Armony, & Grèzes, 2020). This tendency to avoid highly negative individuals, and thus to approach more neutral ones (viewed as much more positive), could lead to stronger contrast effect than those we observed in Study 3. If classical contrast effect is observed on IPD adjustment, it would be interesting to investigate whether it is associated with congruent physiological changes. More precisely, neutral characters embedded in a highly positive context should be perceived as very negative (or threatening). Therefore, we might expect to observe stronger EDA when displayed within the PPS, in accordance with our theoretical proposal.

IV.2. The nature of the relationship between PPS, emotion valence and IPD

Regarding the relation between the physiological response triggered by PLD with angry or neutral FE within the PPS and preferred IPD, we observed a positive linear relation. However, the model we fitted might only capture a small section of the curve, presenting a linear relation (Fig. 38). Hence, even though the relation appears to be linear in this specific section, it might not be true for a larger range of threat. Therefore, even if our stimuli were sufficiently contrasted, it would be worth testing stimuli with a more intense valence to investigate whether this link remains linear or whether it could take another, non-linear, shape. For example, in animals, when a predator is too close, the prey flees at a reasonable distance (Hediger, 1968). Both flight distance and safety distance (after the flight) can be seen as a compromise between cost (energy spent at flight, food lost, etc.) and benefit (security, Ydenberg & Dill, 1986). This compromise therefore suggests that predator A, twice as threatening as predator B, will not be put twice as far as predator B if this distance from B is already far enough. Therefore, it seems more likely that the relation we observed is not linear. At a specific distance, even highly threatening individuals (triggering a strong physiological response in the PPS) should be perceived far enough to ensure body safety. Thus, at a certain point in the curve, the physiological response should increase faster than IPD (convex shape on Fig. 38).

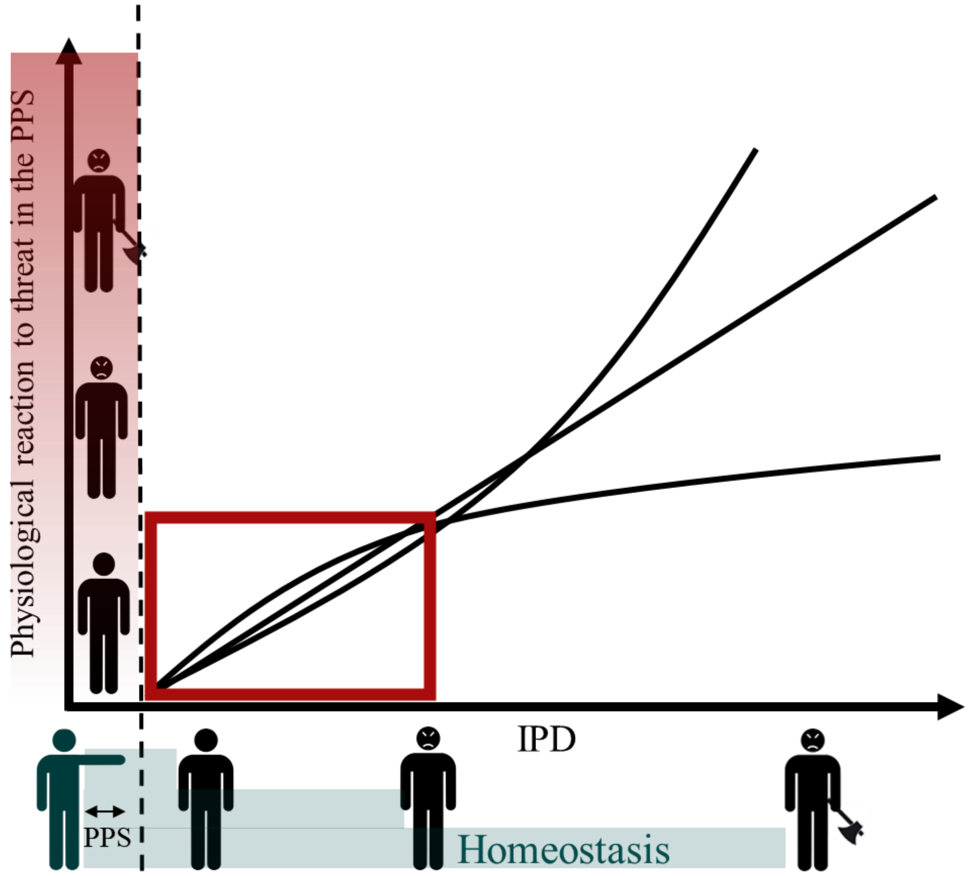

Fig. 38. Schematic representation of different potential functions between the physiological response to threat within the PPS (y axis) and IPD (x axis). The red square represents the portion of the function our data might have captured, resulting in a linear relation. The degree of threat is schematized by: no face: neutral stimuli (no threat); angry face: moderate threat; angry face with an axe: high threat. The origin represents the position of the observer (in green). The dashed line represents the observer's PPS. The red banner represents the increasing physiological response. The green banners (bottom) represent the minimum IPD in order to maintain homeostasis. The axes of the graph are inverted in order to observe a horizontal representation of IPD. Not to scale.

Thus, using stimuli with more intense valence seems relevant for future investigation, whether regarding context effect on IPD adjustment or to better understand the relation between physiological response to threat within the PPS and the adjustment of IPD. In addition, it could be interesting to evaluate different markers of defense mechanisms. Even though new algorithms are increasingly able to cluster the valence of electrodermal responses (Greco, Valenza, Citi, & Scilingo, 2017), EDA is traditionally less sensitive to the emotional valence than to the intensity of emotional stimuli (leading to higher physiological arousal, Boucsein, 2012). In the next section, we will consider the rapid motor responses as potential candidates for studying the contribution of PPS defense mechanisms to the adjustment of IPD.

IV.3. Investigating rapid motor responses

In Study 1 and 2, we focused on the link between IPD adjustment and electrodermal response triggered by individuals within the PPS or violating IPD. EDA reflects the activity of the sympathetic nervous system, in line with action preparation (Boucsein, 2012; Jänig, 2006), but not motor preparation itself. The perception of emotional FE triggers rapid facial and arm reactions from the observer (McIntosh et al., 2006; Moody et al., 2018). Rapid facial reactions would be potentiated by direct eye contact when observing angry FE (Soussignan et al., 2013) and by the intensity of the emotion displayed by the body when observing angry body expressions (Grèzes et al., 2013). To our knowledge, one study investigated the effect of the proximity of characters with angry, neutral or happy FE on rapid facial reactions but no effect was observed (Vanhala et al., 2010). However, these results should be considered with caution since the authors observed an activation of the corrugator supercilii (frowning muscle, involved in the expression of anger) opposite to the one of the virtual character. More precisely, the perception of angry characters led to the suppression of the activity of this muscle whereas happy and neutral characters increased it. Therefore, it would be worth investigating the intensity of rapid facial and arm reactions to threat proximity using more realistic FE (e.g., based on FACS, Ekman & Friesen, 1978).

Overall, considering more intense stimuli and combining physiological measures with motor responses appear to be relevant directions to refine the link between body responses associated to threat perception and IPD adjustment. However, so far, we only focused on how IPD is built on healthy subjects, therefore, it seems natural to consider this question in the future with individuals with psychopathology.

IV.4. A new framework for psychopathological investigations?

As presented in the introduction section, IPD is correlated with the level of social anxiety (Brady & Walker, 1978; Dosey & Meisels, 1969; Givon-Benjio & Okon-Singer, 2020; Iachini, Ruggiero, et al., 2015). Furthermore, individuals with social anxiety disorder show larger physiological responses to social threat (Moscovitch, Suvak, & Hofmann, 2010) and higher somatic sensation due to the social threat (Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004; Domschke, Stevens, Pfleiderer, & Gerlach, 2010; Krautwurst, Gerlach, & Witthöft, 2016). Therefore, if we were to study the relation between the physiological response to threatening individual within the PPS and IPD adjustment, we might expect from this population stronger physiological responses and larger IPD. They should thus be further away on the curve (Fig. 38). However, some authors did not find any increase in the physiological reactivity in patients with anorexia, a disorder associated with social anxiety, in comparison to the one of healthy controls (Ambrosecchia et al., 2017; Nandrino et al., 2011). For example, while anorexic patients reported negative pictures as more arousing than did healthy controls, their EDA did not differ from each other (Nandrino et al., 2011). Indeed, social anxiety can be associated with a tendency to interpret normal body sensations as more negative or more intense than healthy control (Domschke et al., 2010). Therefore, even though anorexic patients experience emotional events as more intense, they might not be physiologically more aroused than healthy controls. Accordingly, the relation between threat perception and the adjustment of IPD might differ in patients with psychopathological disease associated with socio-emotional deficits from the one of healthy control. They might require larger IPD for similar physiological response. As a consequence, they might not be further away on the curve, as suggested above, but they might be represented by another curve, above the one of healthy controls (Fig. 38). This situation could reflect the need for larger margins during social interaction in order to avoid at all cost any physiological activation because it would be perceived too unbearable. If this situation is verified, therapeutic remediation based on biofeedback during social interactions could be considered.

IV.5. Interoception as a crucial component of physiological responses

The ability to adapt IPD as a function of the physiological response triggered by an individual violating the PPS seems intimately related to the ability to perceive the physiological reactions (interoceptive awareness). Interoceptive awareness accuracy varies between individuals that can be classified as people with high or low interoceptive accuracy (Ainley, Apps, Fotopoulou, & Tsakiris, 2016). Individuals with high interoceptive accuracy are thought to be less sensitive to social anxiety and negative affect during social interaction (Mcfadyen et al., 2017; Werner, Duschek, Mattern, & Schandry, 2009). Indeed, as they can access more easily to their physiological changes during social interaction, they could adjust more adequatly emotional and behavioral processes. Conversely, interoceptive accuracy would contribute to autonomic regulation of social behavior. Indeed, individuals with high interoceptive accuracy show increased autonomic reactivity to others' hand within their PPS (Ferri, Ardizzi, Ambrosecchia, & Gallese, 2013). Furthermore, the autonomic reactivity in individuals with high interoceptive accuracy is related to prefered IPD (Ambrosecchia et al., 2017). Therefore, considering interoceptive accuracy as a potential moderator between the physiological response and IPD adjustment seems to be a relevant direction to explore to better understand this relation.

V. CONCLUDING REMARKS

Overall, the present thesis paves the way for new conceptualization of IPD. We argue that IPD is built on PPS representation and depends on defense mechanisms triggered by the emotional valence of others. The adjustment of IPD is thus related to the physiological response triggered by individuals within the PPS and is sensitive to some extent to the emotional context. Therefore, we suggest that IPD adjustment is based on homeostasis. Upcoming investigations should consider interoceptive accuracy as a potential moderator between the physiological response as a proxy of threat perception within the PPS and the adjustment of IPD. Indeed, physiological responses are only useful in IPD adjustment if they are felt and understood.

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APPENDICES

APPENDIX 1: RANGE-FREQUENCY EXAMPLE

Let assume that three independent groups of participants have to estimate the value X of a set of stimuli on a [0-100] continuous scale whose objective value of X are also contained between 0 and 100. Each group has to evaluate 1000000 stimuli and the density of the stimuli on the [0-100] scale can be uniform, positively skewed or negatively skewed (respectively represented in black, red and green in the right panel Fig.1 below and in section II.2.2.3., Fig 13).

The *range* value of a stimulus (R_{ic}) can be mathematically captured by:

$$R_{ic} = \frac{(s_i - s_{min})}{(s_{max} - s_{min})} \tag{1}$$

where S_{min} and S_{max} are respectively the minimum and maximum values of the context when judging a stimulus *i* (S_i representing its objective value, outside of any context) in a context *c*. The *frequency* value can be captured by:

$$F_{ic} = \frac{(k_{ic} - 1)}{(N_c - 1)} \tag{2}$$

where k_{ic} is the rank of the stimulus *i* (S_i) in the context *c* and N_c is the number of stimuli in that context *c*. Hence, according to the range-frequency model an internal judgment *J*, of a stimulus *i* in a context *c* can be formulated as:

$$J_{ic} = w.R_{ic} + (1 - w).F_{ic} \tag{3}$$

where *w* [0; 1] is a relative weight that underlies the compromise between the range and the frequency principles. If *w* = 1, then individuals only consider the range principle and neglect the frequency principle. The opposite is observed if *w* = 0. It is then possible to scale back the internal judgment, via a linear transform according to:

$$T_{ic} = a + b.J_{ic} \tag{4}$$

where T_{ic} is the rescaled rating of the stimulus *i,* in the context *c*, *a*, the minimum value of the scale and *b*, the range of possible ratings.

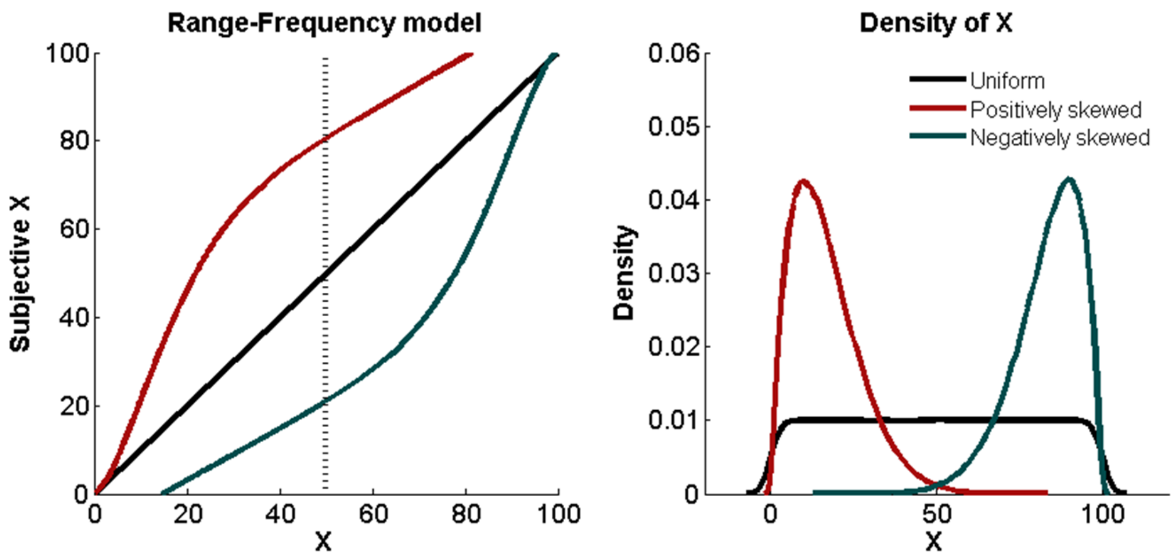

Fig.1. ***Left panel:*** *Simulation of Equation (3) with w fixed at 0.5. Subjective values of the variable X as a function of their "objective" value and depending on their distribution* ***(Right Panel)****. Uniform distribution in black, positively skewed in red and negatively skewed in green.*

For each group, the means (standard deviations) are $\mathbf{M_{black}}$ = 49.99 (28.87); $\mathbf{M_{red}}$ = 16.65 (10.33); $\mathbf{M_{green}}$ = 83.33 (10.34). Assuming that w = 0.5, we can randomly pick a stimulus *i* that exists in the three groups, and calculate its subjective value (T_i) form its objective value S_i. Here, S_i = 66.1356

Black group: given that the stimuli are uniformly distributed, $T_{iblack} = X_{iblack}$ = **66.1356**.

Red group: T_{ired} rank in the distribution = 999852; the minimum objective value S_{minred} = 0.0161 and the maximum S_{maxred} = 78.5215

$$R_{ired} = \frac{(66.1356 - 0.0161\ )}{(78.5215 - 0.0161\ )} = 0.8422$$

$$F_{ired} = \frac{(999852 - 1)}{(1000000 - 1\ )} = 0.9999$$

$$J_{ired} = 0.5 * 0.8422 + (1 - 0.5) * 0.9999 = 0.9210$$

$$T_{ired} = 0 + 100 * 0.9210 = \mathbf{92.104}$$

Green group: T_{igreen} rank in the distribution = 70217; the minimum objective value $S_{mingreen}$ = 10.0106 and the maximum $S_{maxgreen}$ = 99.9851

$$R_{igreen} = \frac{(66.1356 - 1.0.0106\ )}{(99.9851 - 1.0.0106\ )} = 0.6238$$

$$F_{igreen} = \frac{(70217 - 1)}{(1000000 - 1\ )} = 0.0702$$

$$J_{igreen} = 0.5 * 0.6238 + (1 - 0.5) * 0.0702 = 0.3470$$

$$T_{igreen} = 0 + 100 * 0.3470 = \mathbf{34.7002}$$

Thus, a stimulus S_i those objective value is 66.1356 can have different subjective values depending on the context in which it is presented (e.g., 92.1 and 34.7) very far from each other when considering the scale.

APPENDIX 2: PREPRINT DATABASE

Cartaud, A., & Coello, Y. (2020, May 8). ATHOS: a dATabase of 48 3D Human virtual characters with non-emOtional facial expreSsion for virtual reality. Preprint: https://doi.org/10.31234/osf.io/r7fby; Database: https://osf.io/sp938/

Abstract

An increasing number of studies in the Human and Social Sciences and Information and Communication Technologies and Sciences are conducted in virtual reality. Many of them use 3D human-like computer-generated characters in order to study social interactions in healthy participants, or the effect mental illness or neurological disorder on social cognition. However, free access to virtual characters is still not straightforward with often a lack of psychological evaluation of available characters. We present here the ATHOS database composed of 48 Caucasian male and female virtual characters with non-emotional facial expression available in the FBX file format. For each of them, we provide an evaluation in terms of valence, reliability, sympathy and sociability. Concerning these evaluations, inter-rater reliability analysis revealed a good degree of agreement among raters (between 0.85 and 0.98) and a cluster analysis highlighted a division of the virtual characters into three groups (low, medium and high evaluation scores). The ATHOS database of virtual characters, available in open access, can be used for many different purposes including the development of social immersive virtual environments, cognitive assessments or even rehabilitation programs in the health domain.

Keywords: Human virtual character; non-emotional facial expression; 3D environment; virtual reality; inter-rater reliability; cluster analysis, FBX file format

Introduction

Immersive Virtual Reality (IVR) is being increasingly used in everyday life, whether for entertainments, distance learning, advertising, consulting or business activities (Fuchs, Moreau, & Papin, 2001). The expansion of its use is also visible in the field of research with an increasing number of IVR-based studies in the Human and Social Sciences and Information and Communication Technologies and Sciences. Virtual environments offer the possibility of getting closer to ecologic and realistic situations while allowing a strong experimental control (Blascovich et al., 2002; Loomis, Blascovich, & Beall, 1999). Those conditions, often difficult to combine, are essential to improve acceptance of digital devices and replicability of experimental research, which makes virtual reality a precious tool in the domain of perceptual, behavioral, cognitive, affective and social studies.

In order to study social interactions and their effects on cognitive processes, many researches have used naturalistic stimuli such as virtual characters or avatars (Blascovich et al., 2002). Their presence in a virtual environment is sufficient to develop a feeling of social presence (Blascovich et al., 2002), and they are usually used to investigate social cognition and social skills. Virtual characters are for instance of great interest in the study the effects of social constraint on the adjustment of interpersonal distances (Bailenson, Blascovich, Beall, & Loomis, 2003) and the data are consistent with those obtained in real social situations (Iachini et al., 2016). They are also increasingly used in the context of pathological populations for diagnosis and for developing new technological-based therapeutic tools. For instance, virtual characters were used for training social skills in patients with autistic spectrum disorder (Parsons, Leonard, & Mitchell, 2006) or in exposure therapy associated with social anxiety treatments (Anderson et al., 2013).

Despite human-like stimuli are increasingly used in various scientific and applied domains, there is still a limited access to computer-generated virtual characters, in particular those that offer realistic design and are freely available online. We present here an open access database of 48 male and female Caucasian virtual characters with non-emotional facial expression, which was developed at the University of Lille, on the basis of a survey performed online by a number of spontaneous volunteers. The ATHOS database provides for each of the virtual characters an evaluation in terms of valence, reliability, sympathy and sociability. The process for designing and animating the virtual characters is detailed below. The ATHOS database also provides the raw data and a statistical analysis of the reliability of the inter-raters' evaluation as well as a cluster analysis of the stimuli (S1 and S2 Tables).

Method

Participants

The evaluation of the virtual characters was performed online by self-volunteer participants using the LimeSurvey website. The link to the survey was shared on social networks by students in Psychology from the University of Lille (France). From the set of 189 of self-declared participants, only 46 of them completed a minimum of 75% of the survey items and were retained for the data analysis. Among the participants, twenty-seven were females, heighten were males and fourteen did not report their gender. Mean age was 22.11 years (18-36, S.D.= 3.44) and mean study level was 1.80 year after the bachelor's degree (S.D.= 1.56).

Stimuli

Forty-eight Caucasian virtual characters (24 females) with a non-emotional facial expression were created from the Beta version of Adobe Fuse CC, using either the Female or Male "Fit A" model. The proportion of the different body parts was at the medium level according to the scale of the software. All virtual characters had a casual-to-classic dress code including no make-up or jewelry. In order to limit any clipping effect resulting from animation, all virtual characters wore pants. Once created, the virtual characters were exported in OBJ file format and their textures were also saved in PNG file format. The OBJ version of the virtual characters was uploaded to www.mixamo.com in order to be manually rigged. This procedure enabled to associate different animations with each virtual character. Finally, they were exported in FBX file format. The FBX version of each virtual character as well as their textures in PNG and a full-body pictures are available at the following address https://osf.io/sp938/. The file also contains the data related to the individual evaluation.

Evaluation procedure

The evaluation of the virtual characters was performed online using the LimeSurvey website (version 2.63.1) hosted by the University of Lille' servers. The first page of the website provided the instructions concerning the evaluation task. On the second page, participants provided personal information concerning their gender, age and level of education. Then, on the following pages, successive pictures of one virtual character (randomly selected) was displayed above four successive evaluation scales. For each visual character, the evaluation was made by positioning a cursor on a continuous line according to four criteria: valence, reliability, sympathy and sociability. Each criterion was evaluated according to two opposite levels: negative/positive for valence, not reliable/reliable for reliability, unsympathetic/sympathetic for sympathy and not sociable/sociable for sociability. To avoid random evaluation for some of the criteria, participants were instructed to respond to each criterion only if they can provide an evaluation. The completion of the survey took about 25 minutes.

Data analysis

Inter-rater reliability

The degree of agreement among participants (raters) for each evaluation was carried out using Intraclass Correlation Coefficients (ICCs) with the iccNA function (irrNA package, version 0.1.4, Brueckl & Heuer, 2018) of R and R Studio software (version 3.5.1 and 1.1.463 respectively). This function adopts the ICC conventions of Shrout & Fleiss (1979) and allows ICCs computation with missing data by approximating the missing raters' individual effects. ICC estimates and their 95% confident intervals calculation were based on a mean-rating (k = 46 raters), the absolute-agreement, and a 2-way random effects models. The ICC estimate was significant if p-values <.05. Conventionally, estimates less than 0.5, between 0.51 and 0.75, between 0.76 and 0.9, and greater than 0.9 respectively indicated poor, moderate, good and excellent reliability.

Cluster analysis

A cluster analysis was performed using the k-means algorithm (Hartigan & Wong, 1979) from the stats package of R (kmeans function) as a function of the 4 evaluation criteria. The Elbow method was initially used to determine the appropriate number of clusters according to the dataset. The k-means algorithm computed a partition of the virtual characters into different clusters such that the sum of the Euclidian distances between the virtual characters of the clusters and their center was minimized. The algorithm performed 20 iterations in order to enhance the odds of selecting the best clustering model. Then, the Silhouette method was applied for validating the consistency of the assignment of each virtual character to each cluster. Virtual characters with a Silhouette width close to 1 were very well clustered, whereas those close to -1 were likely to be assigned to a wrong cluster. Figs 2 and 3 representing the k-means analysis and the Silhouette method were computed using respectively fviz_cluster and fviz_silhouette functions (factoextra package, version 1.0.5).

Results and Discussion

Considering the different criteria, the evaluation score was on average 5.03 (SD = 2.09) for valence, 4.86 (SD = 2.16) for reliability, 5.15 (SD = 2.23) for sympathy and 5.15 (SD = 2.24) for sociability. S1 Table summarizes the mean, standard deviation and the number of missing ratings for the 4 evaluation criteria and for each virtual character as well as the gender of each virtual character. The number of responses for the criteria considered together was thus 95.21% (4.79 % of missing data).

Inter-rater reliability

Intraclass Correlation Coefficients estimates of each evaluation criterion are reported in Table 1. The corrected mean ratings for each criterion are available in S1 Table (ICC Corrected Mean). The inter-rater reliability analysis for each evaluation criterion revealed a good degree of agreement among the raters (k = 46 participants) with a correlation estimate varying between 0.85 and 0.89. Thus, participants were consistent in their judgement throughout the evaluation of the different virtual characters and they were also consistent with each other.

Table 1: Inter-rater analysis

Criterion	Estimate	p value	95 % CI
Valence	0.88	<0.001	[0.82 - 0.92]
Reliability	0.85	<0.001	[0.78 - 0.9]
Sympathy	0.89	<0.001	[0.85 - 0.93]
Sociability	0.87	<0.001	[0.81 - 0.92]

ICC estimate of the Absolute-Agreement, 95% Confidence Interval and associated p-value per evaluation criterion.

Cluster Analysis

As illustrated in Fig 1, an elbow appeared at k = 3 suggesting that the dataset can be organized in three clusters, corresponding to low, medium and high evaluation scores.

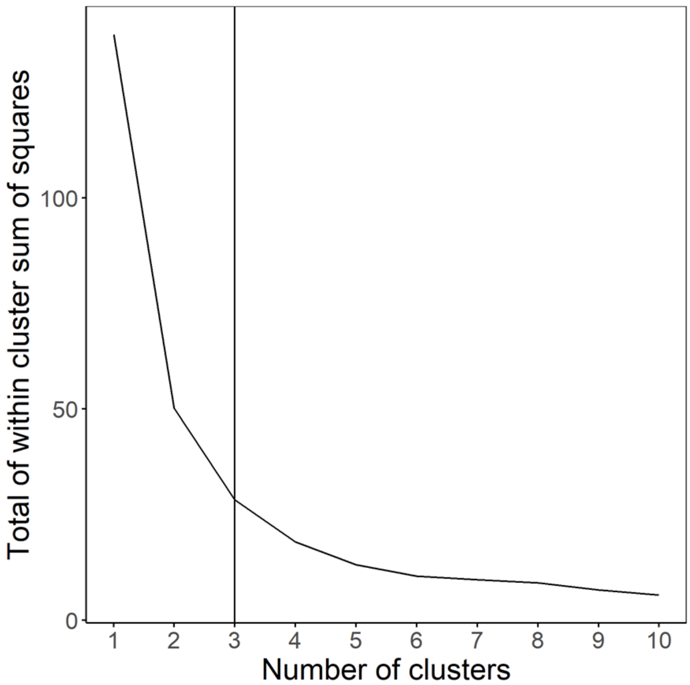

Fig 1. Elbow Plot. Total of within cluster sum of squares as a function of number of clusters computed from Elbow method.

The cluster assignment following the k-means clustering for each virtual character is reported in Table S1 and illustrated in Fig 2. The center of each cluster for each evaluation criterion and the within cluster sum of squares are reported on Table 2. Cluster 1 gathers 13 virtual characters (8 males, 5 females) with higher evaluation scores for every criterion, Cluster 2 gathers 23 virtual characters (12 males, 11 females) with medium evaluation scores for every criterion and Cluster 3 gathers 12 virtual characters (4 males, 8 females) with lower evaluation scores for every criterion. Thus, even though every virtual character was non-emotional, their facial characteristics varied, as a consequence so did their evaluation, resulting in the emergence of three groups of virtual characters. Indeed, the evaluation of an emotionally neutral face can vary depending on the potential structural resemblance of the face with an emotional expression (Said, Sebe, & Todorov, 2009), as it has also been shown in the evaluation of dominance and submissiveness dimensions (Hareli, Shomrat, & Hess, 2009).

Table 2: Cluster analysis

Cluster	Size	Valence	Reliability	Sympathy	Sociability	Sum of Squares
Cluster 1	13	6.1	5.84	6.28	6.23	11.02
Cluster 2	23	4.9	4.75	5.03	5.05	10.91
Cluster 3	12	4.05	3.93	4.03	4.11	6.61

Clusters' size and center for each evaluation criterion, and within cluster sum of squares

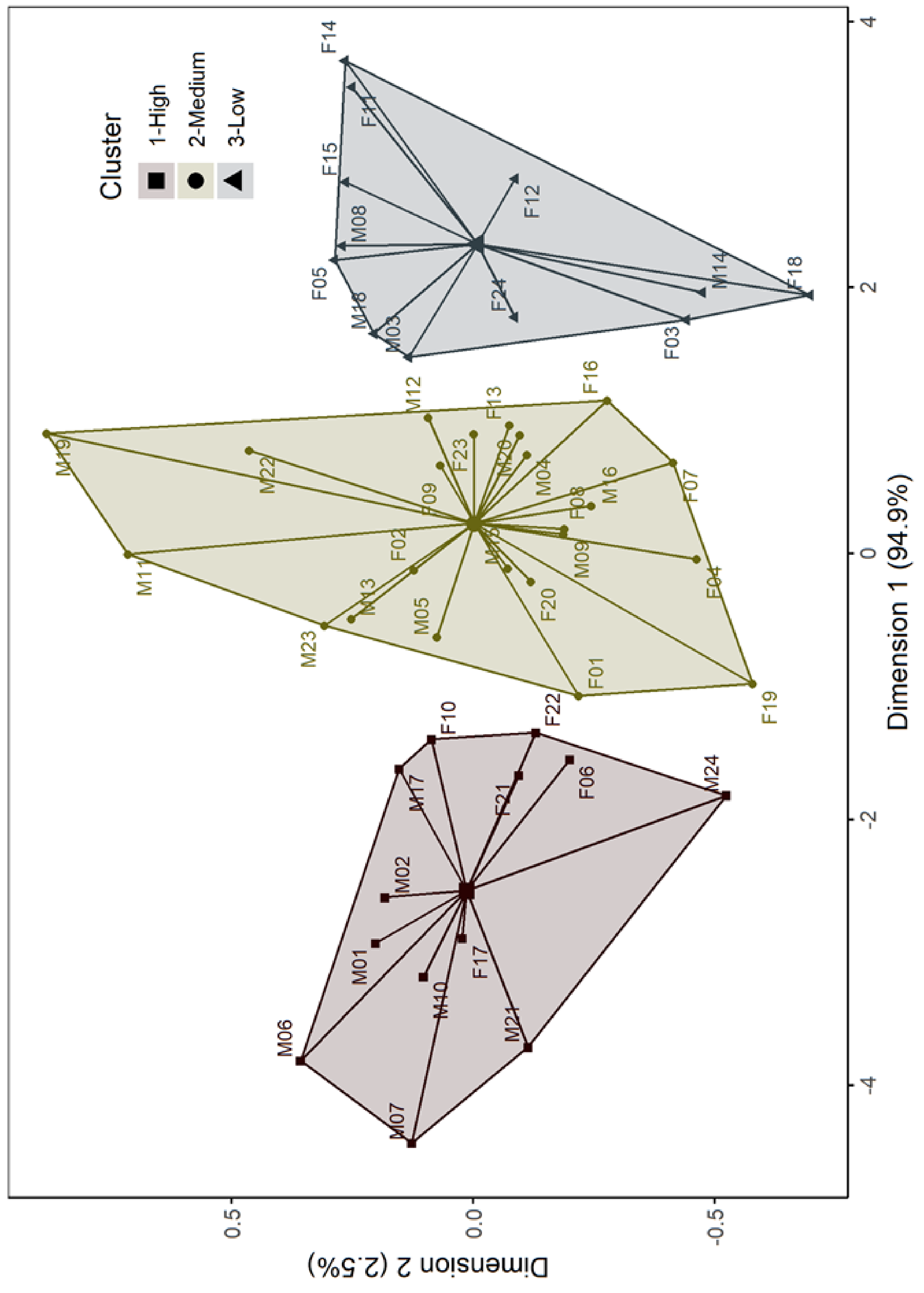

Fig 2. Cluster Plot. Two-dimensional cluster plot of the virtual characters and their associated clusters (high scores: squares, medium scores: circles, low scores: triangles). The (x, y) axes represent the first two components, computed directly from the plot function, are derived from the evaluations of the virtual characters and explain 97.4% of their variability. The larger square, circle and triangle represent the center of each cluster. The distance between each virtual character and its cluster's center represents the distance between them scaled on the two components representation.

The goodness of the assignment of each virtual character to its cluster is illustrated by the Silhouette analysis. Visual analysis of Fig 3 highlighted the reliability of the assignment of each virtual character in its respective cluster, although some of them (width close to 0) could have been assigned to a neighbor cluster. For example, virtual character F01 was assigned to cluster 2 with a score close to 0, indicating that it could have also been assigned to cluster 1, the closer cluster neighbor. These variations can be explained by the non-emotional expression of the virtual characters. Indeed, although the cluster analysis suggested 3 clusters, the center of each cluster varied only little according to the others, due to the small variations of the evaluation scores between the virtual characters. Therefore, one can select virtual characters from this database based on the degree of differences between each other in terms of scores, but also based on their proximity.

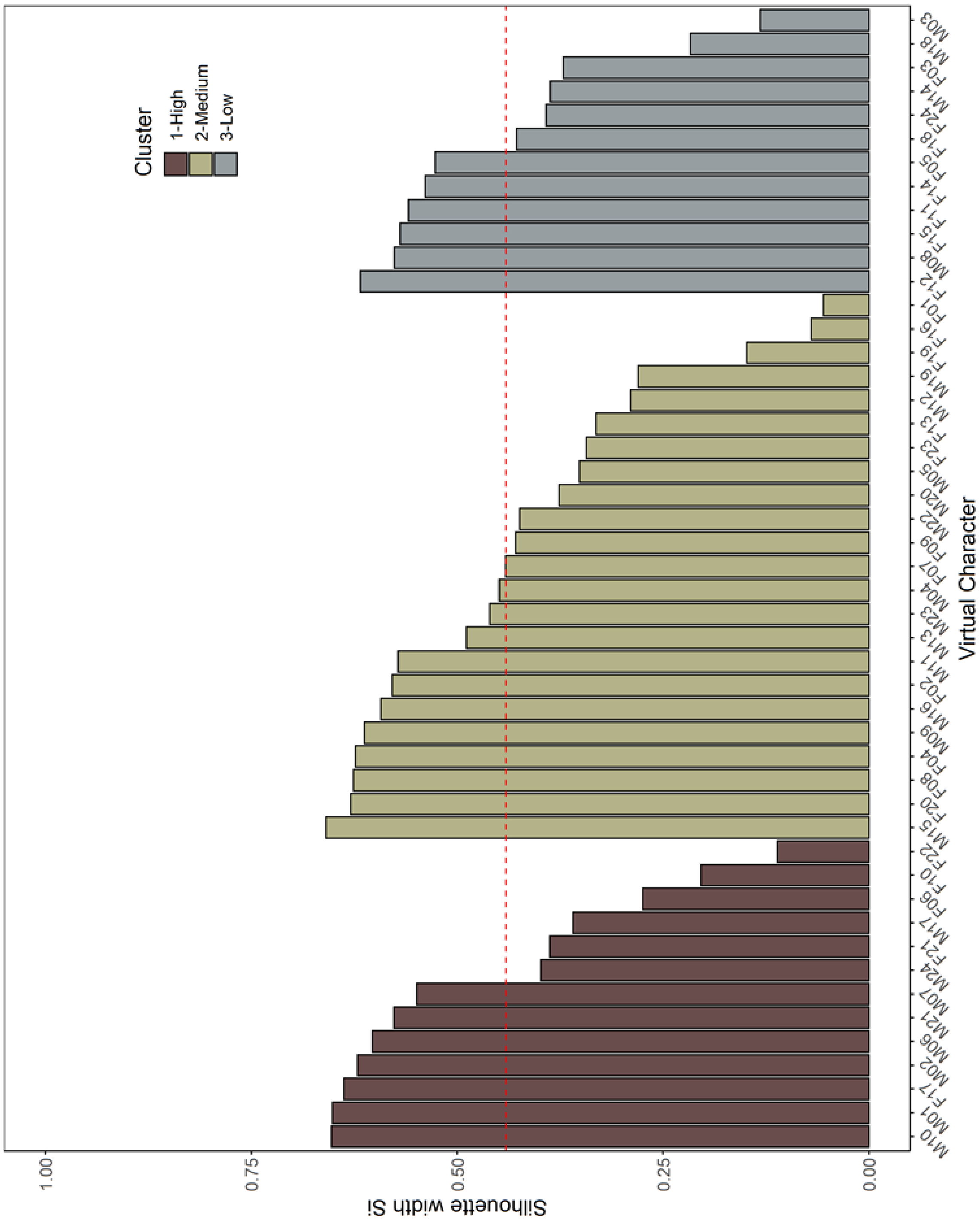

Fig 3. Silhouette Plot. Ordered silhouette width for each virtual character in their cluster. The red Dashed line represents the average silhouette width (0.44).

To our knowledge, ATHOS is the first database of non-emotional virtual characters, freely available online and providing details about design and evaluation. In some previous studies using immersive virtual environment, either little information was provided regarding the design of the virtual characters (Iachini et al., 2016; Seinfeld et al., 2018; Taffou, Ondřej, O'Sullivan, Warusfel, & Viaud-Delmon, 2017), or virtual characters were taken from websites proposing only a few visual attributes often with poor design styles and brief descriptions (Ruggiero et al., 2017). In this context, ATHOS database may represent a valuable tool in VR research as well as applied domains as it is freely available, and includes validated evaluation of realistic visual characters. Indeed, the feeling of social presence in immersive environments seems to depend on the realism of the virtual stimuli (Blascovich et al., 2002). As evidence, Iachini and colleagues (2014) revealed an increase in comfort distance in social interactions when using virtual robots instead of virtual characters. In the same vein, Fini and colleagues (2015) showed that human virtual characters can be used as allocentric frame of reference but not virtual wooden dummies. Furthermore, ATHOS database, combined with head-mounted display, may offer new research avenues in studies looking for an easy to carry installation. The ATHOS database thus offers a number of advantages for virtual reality providing more immersive stimuli and more social presence than simply using videos displayed on a computer screen (Nandrino, Ducro, Iachini, & Coello, 2017) or bulky virtual reality equipment (Cartaud, Ruggiero, Ott, Iachini, & Coello, 2018; Quesque et al., 2017; Taffou et al., 2017; Welsch, Hecht, & von Castell, 2018).

Conclusion

In conclusion, ATHOS database represents the first validated freely available database of male and female Caucasian virtual characters for researches and applications using immersive virtual reality. Furthermore, virtual characters in ATHOS database are compatible with open access software such as Unity or Mixamo, making thus possible their implementation in a virtual environment with specific gait or animation usually also freely available (https://unity.com/). Thus, the ATHOS database paves the way for future research programs in immersive virtual environments, encouraging the development of innovative scenario with improved social presence and enhance potentiality for outcome replicability.

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Supporting information available at https://osf.io/sp938/

APPENDICE 3: METHODOLOGICAL POSTERS: NOT TO DO – EFFECT OF FACIAL EXPRESSIONS ON SOCIAL DISTANCE AND PHYSIOLOGICAL RESPONSES

EFFECT OF FACIAL EXPRESSIONS ON SOCIAL DISTANCE AND PHYSIOLOGICAL RESPONSES

AIM

Quantify the physiological responses (HRV and EDA) and the reachability limit to social stimuli with positive, negative or neutral facial expression

METHOD

Participants:
21 healthy adults

Material:
- 4 m x 2 m vertical 3D screen
- Stereoscopic video projector+ 3D glasses

Stimuli:
- Female and male point-light display (PLD) with a positive, neutral of negative facial expression

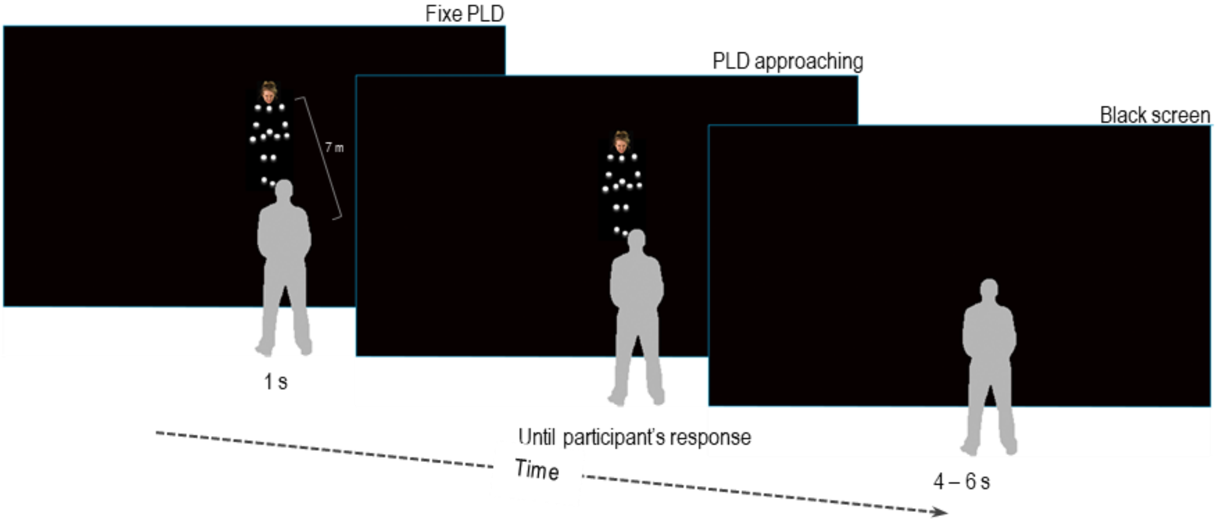
Physiological recording:
- Heart Rate Variability (HRV)
- Electrodermal activity (EDA)

Statistical analysis:
- Mixed models

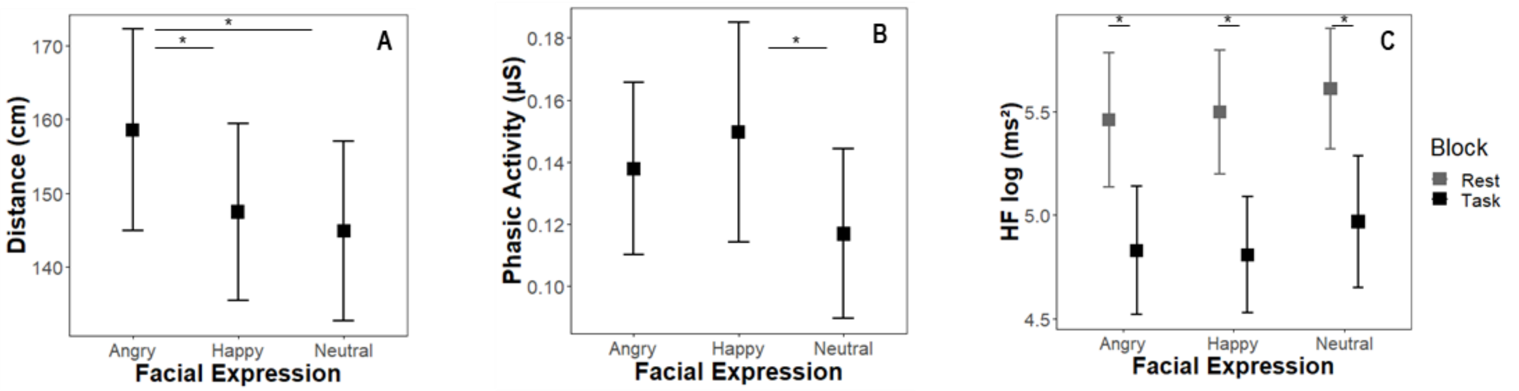
REACHABILITY JUDGMENT TASK

Reachability judgment of the approaching PLD. The PLD disappeared when the participant judged it reachable

Each facial expression was presented in a distinct block (around 3 minutes) preceded by a 3 -minutes rest block



RESULTS



Mean **A)** Reachability distance, **B)** EDA (phasic activity) and **C)** HRV (high-frequency) per facial expression block. Error bars represent the standard errors

METHODOLOGICAL TIPS

Avoid stop distance paradigm for physiological recording to prevent:
- Varying time duration of the stimulus presentation between conditions
- Changes in the physiological response due to proximity

Prefer random presentation to bloc presentation to reduce the expectation effects

APPENDICE 4: METHODOLOGICAL POSTERS: NOT TO DO – EFFECT OF RAPID PRESENTATION OF FACIAL EXPRESSIONS ON SOCIAL DISTANCE AND PHYSIOLOGICAL RESPONSES

EFFECT OF RAPID PRESENTATION OF FACIAL EXPRESSIONS ON SOCIAL DISTANCE AND PHYSIOLOGICAL RESPONSES

AIM

Test whether facial expressions presented at perceptual threshold can modulate the electrodermal response and the interpersonal comfort distances

METHOD

Participants:
28 healthy adults

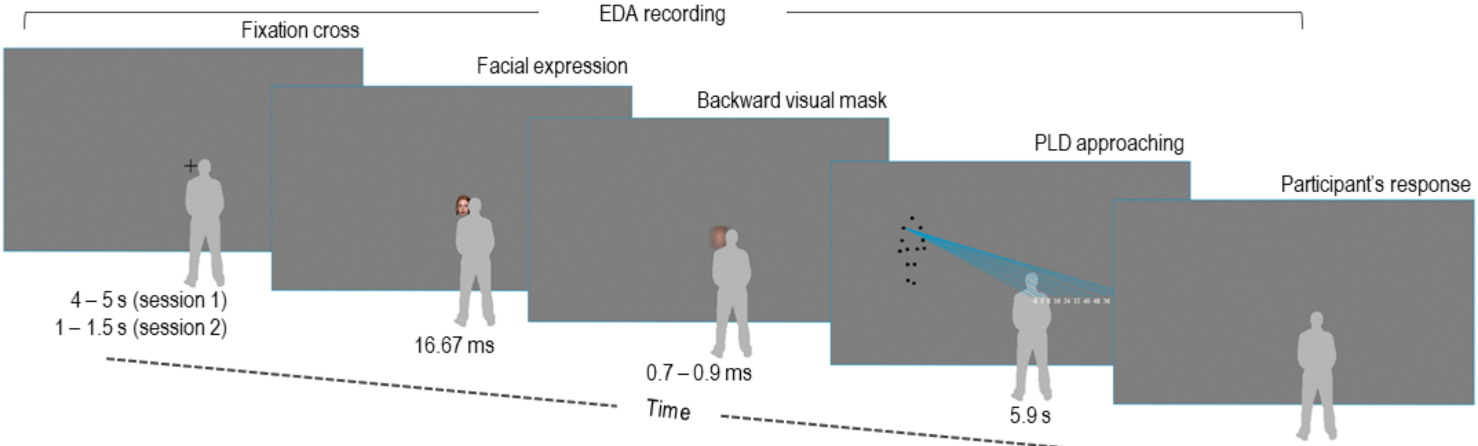
Physiological recording:
- Electrodermal activity (EDA)

Stimuli:
- Female and male point-light display (PLD)
- Positive, neutral of negative facial expressions from the NimStim

Material:
- 4 m x 2 m vertical 3D screen
- Stereoscopic video projector + 3D glasses

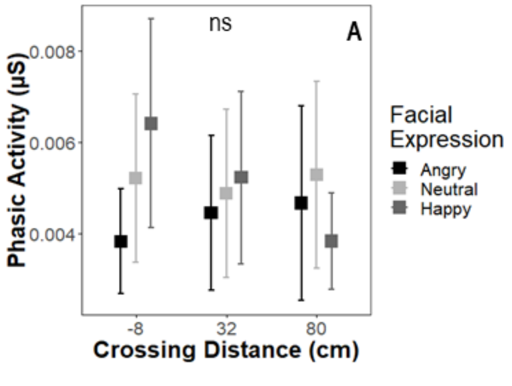
Statistical analysis:
- Mixed models

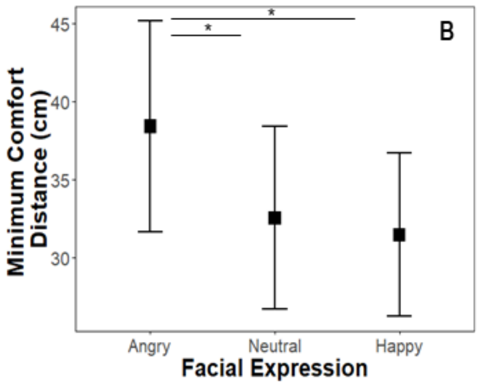
COMFORT JUDGMENT OF INTERPERSONAL DISTANCE TASK



Sequence of events in a trial during the comfort judgement of interpersonal distance task. Participants had to judge whether the PLW crossed their fronto-parallel plane at a comfortable inter-shoulder distance or not (varying between -8 cm to +80 cm by step of 8 cm). PLDs (appearing at 7 m and disappearing at 1.5 m from participants), were preceded by facial expressions (presented at 90 cm from participants). The EDA was recorded during a 1st session (with only -8 cm, 32 cm and 80 cm inter-shoulder distances).

RESULTS





Mean **A)** EDA (phasic activity) and **B)** Minimum comfort distance per facial expression. Error bars represent the standard errors

METHODOLOGICAL TIPS

- Even if it limits retinal persistence, avoid grey background in a dark room when performing a distance estimation task
- Use individual perceptual thresholds
- Use forward visual masks

SECTIONS EN FRANÇAIS

RÉSUMÉ

La distance que maintiennent deux individus entre eux lors d'une interaction sociale (distance interpersonnelle) est particulièrement importante car elle contribue à déterminer la qualité de cette interaction. Une distance trop grande n'est pas propice aux interactions alors qu'une distance trop courte entraîne un sentiment d'inconfort, favorisant les réactions de défense (physiologiques et comportementales). Cette distance interpersonnelle semble être construite sur les représentations spatiales relatives à nos capacités d'actions (ce qui est à portée de main, l'espace péripersonnel) mais dépendante de facteurs sociaux. Ainsi, l'ajustement des distances interpersonnelles repose sur un équilibre subtil entre le besoin d'interagir de façon efficiente avec autrui et le besoin de maintenir une certaine marge de sécurité permettant de se protéger d'un potentiel danger émanant de l'autre. De ce fait, les distances interpersonnelles augmentent en présence d'individus menaçants alors qu'elles diminuent en présence d'individus attrayants. Cet ajustement dépend donc en partie de l'état émotionnel de l'autre, qui peut être identifié via son expression faciale. Cependant, l'évaluation des expressions faciales en termes de valence, peu importe l'émotion, n'est pas absolue car elle dépend également du contexte émotionnel dans lequel les expressions faciales sont présentées.

A cet égard, l'objectif de cette thèse était double : (1) qualifier la relation entre distance interpersonnelle et la réponse physiologique produite par la perception d'individus plus ou moins menaçants présents dans l'espace péripersonnel ; (2) quantifier l'effet du contexte émotionnel sur l'ajustement des distances interpersonnelles. Grâce à un système de réalité virtuelle, optimisant le sentiment d'immersion et favorisant l'observation de réponses physiologiques et comportementales « authentiques », nous avons mis en évidence une relation linéaire entre la réponse physiologique et l'ajustement des distances interpersonnelles. De plus, nos données ont pu révéler que l'effet de contraste induit par le contexte émotionnel lors de jugements de valence (décalage vers la direction opposée à celle du contexte émotionnel) altérait également, mais de façon plus subtile l'ajustement des distances interpersonnelles.

Dans l'ensemble, les résultats de cette thèse suggèrent que l'ajustement des distances interpersonnelles repose à la fois sur la représentation de l'espace péripersonnel et le contexte émotionnel. Nos données supportent que l'ajustement des distances interpersonnelles repose sur le besoin d'homéostasie lors d'interactions sociales, en lien avec la valeur défensive de l'espace péripersonnel. Cette distance maintenue à l'égard des autres, nécessaire pour assurer l'homéostasie, peut être quantifiée à partir de la réponse physiologique déclenchée par ces mêmes individus lorsqu'ils sont présents dans l'espace péripersonnel. Au-delà de l'apport de nouvelles connaissances sur le lien entre la représentation de l'espace péripersonnel, le traitement des émotions et les distances interpersonnelles, la présente thèse fournit un nouveau cadre théorique qui pourrait être pertinent pour des investigations cliniques, en tenant compte notamment de la sensibilité à percevoir les informations intéroceptives.

Mots-clés : Distances interpersonnelles – Menace – Réponse physiologique – Espace péripersonnel – Expressions faciales émotionnelles – Contexte émotionnel – AED

ETUDE 1

Avant-propos

L'objectif de cette première étude était de vérifier l'hypothèse principale de cette thèse qui est que nos réactions physiologiques à un stimulus menaçant peuvent être codées en termes de distance. Nous voulions donc dans un premier temps analyser l'effet de l'état émotionnel d'autrui, véhiculé par son expression faciale, sur les réponses physiologiques ainsi que sur l'ajustement des distances interpersonnelles. Nous voulions ensuite étudier s'il existait une relation entre ces distances interpersonnelles et les réponses physiologiques associées à la présentation des stimuli sociaux négatifs et neutres. Lors de cette étude, réalisée en réalité virtuelle, les participants devaient tout d'abord estimer si des point-light-displays, ayant une expression faciale de joie, de colère ou neutre étaient atteignables ou non pendant que leur activité électrodermale était enregistrée. Les mêmes participants devaient ensuite estimer si la distance à laquelle les mêmes stimuli les croisaient était confortable ou non. Leur dernière tâche consistait à évaluer les expressions des acteurs en termes de valence et d'activation physiologique. Cette étude a été précédée d'une étude préliminaire dont un poster méthodologique est disponible en annexe 3.

Résumé

Un contrôle adapté des distances interpersonnelles dans les contextes sociaux est un déterminant important de la qualité des interactions sociales. Bien que les distances interpersonnelles semblent dépendantes de facteurs sociaux tels que le sexe, l'âge ou l'activité de notre interlocuteur, elles semblent également sensibles à la façon dont nous représentons notre espace péripersonnel. Afin de tester cette hypothèse, nous avons étudié la relation entre les réponses émotionnelles, mesurées via l'activité électrodermale (AED), déclenchées par des personnages (point-light-displays humanoïdes, PLD) ayant différentes expressions faciales (neutre, colère, joie) lorsqu'ils étaient présentés dans l'espace péripersonnel des participants et la distance interpersonnelle de confort avec ces mêmes PLD lorsqu'ils croisaient l'axe fronto-parallèle des participants. Les résultats ont mis en avant une augmentation de l'activité phasique de l'AED pour les PLD avec une expression faciale de colère lorsqu'ils étaient présents dans l'espace péripersonnel (tâche de jugement d'atteignabilité) par rapport aux mêmes PLD présents dans l'espace extrapersonnel. Cette augmentation n'a été observée que pour les PLD avec cette expression faciale. Les résultats ont également mis en avant une augmentation de la distance de confort pour les PLD avec une expression faciale de colère (tâche de jugement de confort sur les distances interpersonnelles) par rapport aux PLD avec une expression faciale de joie ou neutre. De plus, cette augmentation des distances interpersonnelles était en lien avec l'augmentation des réponses physiologiques. Ainsi, les résultats indiquent que la distance interpersonnelle minimum peut être en partie prédite à partir de la réaction émotionnelle déclenchée par autrui lorsqu'il est présent dans l'espace péripersonnel. Cela suggère que l'espace péripersonnel d'action et l'espace social interpersonnel sont sensibles à la valence émotionnelle d'autrui de façon semblable. Cela peut refléter un mécanisme d'adaptation commun sous-jacent aux interactions avec l'environnement physique et social, mais dont la fonction est également d'assurer la protection du corps contre les menaces potentielles.

ETUDE 2

Avant-propos

Le but de cette deuxième étude était d'analyser si les effets observés lors de l'étude 1 pouvaient être observés lorsque les expressions faciales étaient présentées au seuil perceptif. En effet, il est assez fréquent de n'apercevoir que de façon subreptice les expressions faciales d'autrui. Cette étude était donc relativement écologique vis-à-vis des situations de la vie quotidienne. Lors de l'étude précédente, nous avons pu mettre en avant une modulation des distances interpersonnelles de confort en fonction de l'expression émotionnelle d'autrui. Cela se traduisait par une augmentation de cette distance si le stimulus avait une expression faciale de colère par rapport à s'il avait une expression faciale de joie ou neutre. Nous avons également observé une augmentation de la réponse physiologique, mesurée via l'activité électrodermale, lorsque les stimuli avec une expression faciale de colère étaient présents dans l'espace péripersonnel des participants par rapport à s'ils étaient dans l'espace extrapersonnel. L'activité électrodermale enregistrée lors de la présentation de ces personnages avec une expression faciale de colère dans l'espace péripersonnel était également plus importante que celle enregistrée avec les personnages ayant une expression faciale neutre dans l'espace péripersonnel. Nous avons enfin pu mettre en avant une relation linéaire entre la réponse physiologique déclenchée par les stimuli menaçants (avec une expression faciale de colère) et neutres lorsqu'ils étaient présentés dans l'espace péripersonnel et la distance minimum tolérée entre les participants et ces mêmes stimuli. En effet, plus les stimuli déclenchaient une réponse autonome forte, plus la distance interpersonnelle de confort augmentait avec ces stimuli.

Lors de cette deuxième étude, nous avons tout d'abord proposé une tâche de catégorisation d'expressions faciales (colère, joie, neutre). Nous faisions varier la luminance des images qui étaient présentées pendant 16 ms (temps d'affichage minimum de l'écran) afin d'établir un seuil perceptif individuel qui serait utilisé dans les tâches suivantes. Ensuite, les participants réalisaient une tâche de jugement de confort des distances interpersonnelles entre eux et un PLD qui les croisait à différentes distances. Ces PLD étaient précédés par la présentation de la photo d'un acteur (nouveau set d'acteurs) avec une expression faciale (colère, joie ou neutre) présentée au seuil perceptif individuel préalablement établi. Cette tâche était divisée en deux sessions. Lors de la première session la réponse électrodermale était enregistrée et seulement 3 distances de croisement étaient présentées (collision entre les épaules, au seuil de confort moyen établi lors de l'étude 1 et à une distance confortable). Lors de la seconde session seule la réponse comportementale (jugement de confort) était enregistrée, il y avait donc beaucoup plus de distances présentées et donc d'essais. La dernière tâche consistait à évaluer le ressenti physiologique lors de la perception des expressions des acteurs (faible ou forte activation physiologique). Cette étude a été précédée d'une étude préliminaire dont un poster méthodologique est disponible en annexe 4.

Résumé

La distance interpersonnelle, composante essentielle des interactions sociales, est modulée par l'émotion véhiculée par autrui et la réponse physiologique associée. Cependant, dans nos sociétés caractérisées par des environnements hyper-stimulants et surpeuplés, nous ne pouvons parfois apercevoir que de façon subreptice les expressions faciales des autres afin d'ajuster notre comportement. La façon dont cela impacte les interactions sociales n'est pas encore très bien comprise. Pour étudier cette problématique, nous avons analysé si les expressions faciales difficilement perceptibles modifient la réponse physiologique (activité électrodermale, AED) et le jugement de confort sur des distances interpersonnelles. Nous avons enregistré l'AED des participants pendant qu'ils réalisaient une tâche de jugement de confort sur des distances interpersonnelles avec un Point-Light Display (PLD). Ce PLD, avec une démarche émotionnellement neutre, marchait vers les participants en les croisant à différentes distances après que ces derniers aient été exposées à des expressions faciales positives (joie), négatives (colère) ou neutres présentées au seuil perceptif. L'analyse bayésienne des données a révélé une augmentation/diminution des distances interpersonnelles de confort avec le PLD en fonction de la valence négative/positive de l'expression faciale. Elles ont également mis en avant une augmentation de l'AED lorsque le PLD franchissait la distance interpersonnelle de confort des participants après qu'ils aient été exposés à des expressions faciales de colère. Ces effets étaient corrélés avec l'évaluation de l'activation physiologique subjective des expressions faciales. Ainsi, une exposition préalable à des expressions faciales difficilement perceptibles peut modifier les représentations de l'espace social de confort et les réponses physiologiques associées à une violation des distances interpersonnelles de confort, en fonction de la valence et de l'activation physiologique perçue des stimuli sociaux.

ETUDE 3

Avant-propos

Cette troisième étude avait pour but de s'intéresser à l'effet du contexte émotionnel sur l'ajustement des distances interpersonnelles avec des personnages neutres en favorisant cette fois-ci l'émergence d'un effet de contraste. Lors de l'étude 2, les expressions faciales émotionnelles étaient présentées au seuil perceptif juste avant l'apparition du PLD et cela était suffisant pour modifier les distances interpersonnelles. Elles étaient néanmoins présentées au niveau de la position de la tête du PLD ce qui offrait une forte contiguïté spatiale et temporelle, favorisant l'émergence d'un effet d'assimilation de la valence du stimulus émotionnel au stimulus neutre. Cette fois-ci, nous voulions étudier si en retirant la valeur émotionnelle du stimulus et en la déplaçant dans l'environnement, cette valence aurait un impact sur l'ajustement des distances interpersonnelles avec des personnages ayant une expression faciale neutre. Il est bien connu que le contexte émotionnel modifie notre représentation d'un individu. Lorsqu'un effet de contraste est observé, un stimulus neutre est évalué comme plus positif s'il est présenté dans un contexte négatif que s'il est présenté dans un contexte positif.

Nous avons donc réalisé une étude en ligne où nous avons demandé aux participants répartis en deux groupes d'évaluer des personnages cibles avec une expression faciale neutre après qu'ils aient été présentés dans un contexte dont les personnages avaient une expression faciale de colère (groupe A) ou de joie (groupe B). Les personnages cibles et contextuels défilaient successivement de façon aléatoire les uns après les autres à l'écran. Ensuite, les participants réalisaient une tâche de jugement des distances interpersonnelles avec ces mêmes personnages. Lors d'une seconde session, les participants réalisaient les mêmes tâches mais les personnages constituant le contexte émotionnel du groupe A avaient cette fois-ci une expression faciale de joie alors que ceux du groupe B, une expression faciale de colère. Comme les distances interpersonnelles sont dépendantes de la valence du stimulus, si nous observions un effet de contraste du contexte sur l'évaluation des personnages neutres, nous nous attendions à ce que cela s'observe également au niveau des distances interpersonnelles.

En parallèle de cette expérience, nous avons réalisé une tâche contrôle durant laquelle trois groupes indépendants devaient évaluer les personnages utilisés dans l'expérience en termes de valence. Chaque groupe était assigné à un set d'expressions faciales (joie, colère ou neutre). Ces résultats nous ont permis de réaliser des prédictions quant aux résultats que nous devrions observer lors de l'expérience, à savoir, un effet de contraste fort sur les jugements de valence lors de la première session disparaissant lors de la seconde session.

Résumé

Certaines études ont mis en avant la relation entre la valence émotionnelle de stimuli sociaux et l'ajustement des distances interpersonnelles avec ces mêmes stimuli. Ici, nous avons étudié si l'effet de contraste induit par contexte émotionnel sur les jugements de valence affecte également l'ajustement des distances interpersonnelles. Dans cette étude en ligne, 51 participants observaient successivement des personnages virtuels masculins et féminins présentant une expression faciale neutre (deux personnages) ou émotionnelle (10 personnages avec des expressions faciales de colère ou de joie). Après chaque présentation, les participants évaluaient la valence (positive-négative) des personnages neutres et émotionnels et réalisaient une tâche de jugement des distances interpersonnelles (appropriées ou non) avec ces mêmes personnages. Nous avons observé un effet de contraste classique sur les jugements de valence, mais cet effet de contraste n'affecte que légèrement le jugement des distances interpersonnelles. Ainsi, bien que le contexte émotionnel influence les jugements de valence de stimuli sociaux, il n'a qu'un faible effet sur l'ajustement des distances interpersonnels, qui semble principalement reposer sur l'information catégorielle de l'expression faciale du stimulus social avec lequel nous interagissons.

ETUDE 4

Avant-propos

Cette dernière étude a été réalisée et rédigée lors de la fin du confinement qui a débuté en mars 2020. En plus de nous intéresser aux distances interpersonnelles dans un contexte de crise sanitaire lors duquel la distanciation sociale faisait, et fait encore, partie des gestes barrières à adopter pour limiter la propagation du virus, nous avons pu étudier comment l'ajustement des distances interpersonnelles était modulé par une caractéristique physique qui n'était pas l'expression faciale émotionnelle : le port du masque. En effet, lors de la période qui a précédé le déconfinement, nous ne savions pas encore comment le port du masque serait vécu en termes de perception de la menace ; il pouvait être vu comme un signal sécurisant (« si cette personne porte un masque, alors elle me protège de la maladie ») ou comme un signal rappelant le contexte sanitaire (« ce masque me rappelle que je dois appliquer les gestes barrière et maintenir mes distances avec cette personne »). Lors de cette étude en ligne (du fait du confinement), des personnages apparaissaient successivement à l'écran des participants à différentes distances d'eux dans une salle vide. Ils pouvaient avoir une expression faciale de joie, de colère, neutre ou porter un masque de type chirurgical. Les participants devaient estimer si ces personnages se trouvaient à une distance appropriée pour interagir avec eux ou non (trop proche). Après cette tâche, les participants évaluaient les personnages en termes de menace, confiance, détermination et niveau de santé. Les résultats obtenus sont présentés dans la section intitulée Study 4. Nous prévoyons de relancer cette étude afin d'étudier si (et comment) le comportement des individus évolue vis-à-vis de l'ajustement des distances interpersonnelles avec le temps relativement au port du masque.

Résumé

Dans le contexte actuel de pandémie, les gestes barrière tels que se laver les mains régulièrement, la distanciation sociale et le port du masque sont hautement recommandés. En parallèle, les distances interpersonnelles sont particulièrement sensibles à la dimension affective des interactions sociales, dimension pouvant être impactée par le contexte sanitaire actuel de la Covid-19. Dans cette expérience menée en ligne, nous avons étudié la distance interpersonnelle que préféraient 457 participants français vis-à-vis de personnages virtuels portant un masque ou présentant une expression faciale de joie, neutre ou de colère. Les résultats suggèrent que port du masque entraine une diminution significative de la distance interpersonnelle et une augmentation du ressenti de confiance par rapport aux personnages des autres conditions. De plus, la distance interpersonnelle semble réduite pour les personnes ayant été (ou étant) atteintes de la Covid-19 ou vivant dans des départements peu touchés par la pandémie alors qu'elle ne semble pas affectée par le niveau de santé perçu des personnages. Ces résultats apportent de nouvelles perspectives sur les facteurs psychologiques qui motivent l'ajustement des distances interpersonnelles, notamment en contexte de menace collective. Ils sont aussi particulièrement importants car, malgré l'importance incontestable du port d'un masque dans le contexte actuel de la pandémie, l'utilisation du masque doit s'accompagner d'une distanciation sociale afin de prévenir les conséquences potentiellement néfastes sur la santé.