# Assessments and Applications of Information Communication Technologies in Autism Spectrum Disorder Treatment

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# Assessments and Applications of Information Communication Technologies in Autism Spectrum Disorder Treatment

Doctoral Thesis in Cognitive Science

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# *Abstract*

The increasing research focus of Information Communication Technologies (ICT) in therapeutic and educational approaches for children with Neurodevelopmental Disorders (NDD), raises crucial questions about the design conception of these tools and its effectiveness. ICT are suggested to provide new opportunities to enhance social and communication skills, cognitive functioning, and overall quality of life for children with special needs.

The work of this thesis is structured around two part incorporating engineering and clinical perspectives. The assessment part investigated how ICT for NDD care are conceived in terms of design. To answer this objective, we created the first transtechnology inventory with the support of a Delphi validation, aiming to assess the design of therapeutic and education ICT for NDD care. We also conducted a systematic meta review allowing us to contextualize the evolution of ICT research concerning implications for design and research methodology choices.

The clinical perspective explored two therapeutic ICT interventions for social skills training for Autism Spectrum Disorder (ASD). To answer this objective, we conducted a feasibility and usability study of a robotic intervention in a social skills group. At last, we finalized the protocol of a randomized control trial of a home-based delivered serious game intervention investigating its efficacy and medico-economic implications.

In conclusion, this thesis demonstrates that ICTs can be valuable tools in providing innovative approaches to treating individuals with NDD. However, it emphasized the significant importance of design choices when developing digital therapeutic tools. It does so by providing the first ICT Inventory, which encompasses a coordinated vision between engineering and clinical perspectives. DICTI aims to provide an easy tool to guide ICT developers into considering clinical objectives related to design features. Moreover, it aims to make a valuable contribution to the ICT field by proposing

two therapeutic technological tools implemented in ASD care. The development of the DICTI is of significant relevancy in the assessment of the R2C3 robotic interface, as it proposes a more suitable version for a future repeatability study.

**Keywords:** neurodevelopmental disorders, autism spectrum disorder, information communication technologies, design, efficacy, social robots, serious games.

# *Résumé*

La croissante focalisation de la recherche sur les Technologies de l'Information et de la Communication (TIC) dans les approches thérapeutiques et éducatives pour les enfants atteints de Troubles Neurodéveloppementaux (TND) soulève des questions cruciales quant à la conception de ces outils et à leur efficacité. Les TIC sont suggérées comme offrant de nouvelles opportunités pour améliorer les compétences sociales et de communication, le fonctionnement cognitif et la qualité de vie globale des enfants ayant des besoins particuliers.

Le travail de cette thèse est structuré autour de deux parties intégrant des perspectives d'ingénierie et cliniques. La première partie de l'évaluation a examiné comment les TIC pour les soins des TND sont conçues en termes de design. Pour répondre à cet objectif, nous avons créé le premier inventaire transtechnologique avec le soutien d'une validation Delphi, visant à évaluer la conception des TIC thérapeutiques et éducatives pour les soins des TND. Nous avons également réalisé une méta-analyse systématique nous permettant de contextualiser l'évolution de la recherche sur les TIC en ce qui concerne les implications pour les choix de conception et de méthodologie de recherche.

La perspective clinique a exploré deux interventions thérapeutiques des TIC pour la formation aux compétences sociales du Trouble du Spectre de l'Autisme (TSA). Pour répondre à cet objectif, nous avons mené une étude de faisabilité et d'utilisabilité d'une intervention robotique dans un groupe de compétences sociales. Enfin, nous avons finalisé le protocole d'un essai contrôlé randomisé d'une intervention de jeu sérieux délivrée à domicile, étudiant son efficacité et ses implications médico-économiques.

En conclusion, cette thèse démontre que les TIC peuvent être des outils adaptés pour fournir des approches innovantes pour le traitement des personnes atteintes de TND. Cependant, elle souligne l'importance significative des choix de conception lors du développement d'outils thérapeutiques numériques. Elle le fait en fournissant le premier Inventaire des TIC, qui englobe une vision coordonnée entre les perspectives d'ingénierie

et cliniques. Le DICTI vise à fournir un outil simple pour guider les développeurs de TIC à prendre en compte les objectifs cliniques liés aux caractéristiques de conception. De plus, elle vise à apporter une contribution précieuse au domaine des TIC en proposant deux outils technologiques thérapeutiques mis en œuvre dans les soins du TSA. Le développement du DICTI est d'une pertinence importante dans l'évaluation de l'interface robotique, car il nous a permis de proposer une version plus adaptée pour une future étude de reproductibilité.

**Mots-clés:** troubles neurodéveloppementaux, trouble du spectre de l'autisme, technologies de l'information et de la communication, conception, efficacité, robots sociaux, jeux sérieux.

# *Foreword*

My doctoral research was structured to embrace Information and Communication Technologies (ICT) within the field of Neurodevelopmental Disorders (NDD), focusing specifically on Autism Spectrum Disorder (ASD). While collaborating with my tutors, Professors David Cohen and Mohamed Chetouani, our goal was to explore a wide range of scientific and clinical contexts, where ICTs could be applied. This implied adopting a multidisciplinary approach that integrated clinical, psychopathological, developmental, engineering and ICT design perspectives.

In terms of research objectives, we had the opportunity to be implicated in two extensive treatment studies, allowing us to employ computational approaches in two distinct ways. Firstly, we utilized computational analyses to assess prognostic factors related to ASD, including the impact of treatments given to autistic children. This data was made available to us by Dr. Nicole Garret-Gloanec, principal investigator of the EPIGRAM prospective study. Secondly, as a tool to provide therapeutic training through a serious game e-GOLIAH, a technological parent-delivered intervention at home. This innovative therapeutic training tool was intended to be evaluated through a randomized controlled trial, which unfortunately faced delays due to COVID pandemics and lockdowns. As a result, the timeline and scope of my thesis was adjusted accordingly.

The objective of the Epigram study was to explore prognostic factors of ASD after one year of treatment given in French day care hospitals and following Integrative Care Practices recommendations (ICPs, Squillante et al., 2022). During the first two years of my PhD, we collaborated with Dr. Nicole Garret-Gloanec and her team on the analysis of the EPIGRAM study, a naturalistic treatment study of children with severe ASD. This study included 89 autistic children aged less than 6 years and receiving ICPs. Unlike most previous studies, we included participants with low economic status, migrant status, and low ASD functioning. We used two complementary modeling approaches, including multivariable regression models and machine learning (Classification and Regression Tree, CART). Notably, our results revealed that migration negatively impacted the one-year outcome (Bettencourt et al., 2022), while emotion/behavior interventions led to significantly better one-year outcomes (Bettencourt et al., in submitted).

Additionally, I collaborated with my co-tutor, Charline Grossard, on developing the first ICT Inventory through a Delphi study (Grossard et al., 2023). We also conducted a meta-analysis investigating the evolution of ICTs over the last few decades, examining the ICT design and research methodology implications (Grossard et al., submitted).

Although my planned experimental PhD work with e-GOLIAH, a serious game inspired by the Early Start Denver Model (ESDM), was delayed, we adapted and carried out a retrospective study exploring the hypothesis that screen overexposure could lead to symptoms similar to ASD, which might regress after removing access to electronic screens. The initial sample included 15 patients described as secondary ASD due to screen overexposure. The study revealed that ASD stereotypical behaviors diminished following screen removal, parental involvement, and improved play quality. However, due to the study design, small sample size and lack of heterogeneity in clinical variables across participants, we could not make generalizable or trustworthy conclusions. Nevertheless, this experience taught me the importance of rigorous, well-designed methodology in evidenced-based research.

Furthermore, while at the research lab at the child psychiatry department of the Pitié Salpêtrière Hospital and the Institut des Systèmes Intelligents et de Robotique (ISIR), I witnessed my colleagues naturalistic observational research with robots and children with NDD. The Co-Writer project, a remarkable robotic and serious game intervention aiming to help children with dysgraphia, truly caught my attention. The Co-Writer project implemented a learning-by-teaching paradigm, where children taught the robot to improve its handwriting skills through a tablet, leading to improved writing skills, self-esteem and confidence (Gargot et al., 2020).

My interest for ASD care was awakened during my time in NYC when I volunteered at a center for child development, in a social skills group pairing neurotypical children and teens with autistic children. This experience, led me to become the mentor coordinator and eventually the program co-director—using my interpersonal skills, creativity, and understanding of ASD to develop social skills programs for the center involving physical expression, arts and craft, sports, and social games.

During my third PhD year, due to the continuous uncertainty of the e-GOLIAH trial, we continued exploring alternative options. The possibility of implementing the

Rehabilitation Robotic Companion for Children and Caregivers (R2C3) robotic interface from the Co-Writer project in a social skills group for autistic children came up (Zou et al., 2022). Combining my clinical experience with my interest in social robotics, this multidisciplinary collaborative research experience became one of the highlights of my PhD. We conducted one of the first exploratory clinical trials investigating the feasibility and usability of a social robot, the Wizard of Oz Rehabilitation Robotic Companion for Children and Caregivers (R2C3) interface, in a social skills group for autistic children. Although both active and inactive robotic interfaces showed no significant differences, the use of the robot resulted in increased engagement and interaction initiations, likely due to the novelty effect. Furthermore, including a robot in the social skills group did not hinder the intervention's effectiveness (Bettencourt et al., submitted). Our future work involves adapting the R2C3 interface to the group's needs and developing an efficacy design protocol.

# *Publications* *Original articles related to the thesis:*

Grossard, C., Bettencourt, C., Kellems, R., Chetouani, M., & Cohen, D. (2023). Building the design ICT inventory (DICTI): A Delphi study. *Computers in Human Behavior Reports*,*9*,100261.

Bettencourt, C., Grossard, C., Segretain, M., Bree, M., Pellerin, H., Anzalone, S., Chetouani, M., & Cohen, D. (2023) Investigating the feasibility and usability of the Wizard of Oz robotic interface R2C3 in a social skills group for autistic children: an exploratory study (submitted)

## *Literature review articles:*

Bettencourt, C., Grossard, C., Anzalone, S., Chetouani, M., & Cohen, D. (2021). Robotica e trattamento dei disturbi del neurosviluppo: revisione della letteratura. *Prosp. Pediatr*, *51*,1-9.

Bettencourt, C., Anzalone, S., Chetouani, M., & Cohen, D., Grossard, C. (2023). Have information and communicative technologies research for neurodevelopmental disorders improved overtime? A systematic meta-review (submitted)

## *Original articles not related to the thesis:*

Bettencourt, C., Garret-Gloanec, N., Pellerin, H., Péré, M., Squillante, M., Roos-Weil, F., ... & Cohen, D. (2022). Migration is associated with baseline severity and progress over time in autism spectrum disorder: Evidence from a French prospective longitudinal study. *Plos one*,*17*(10),e0272693.

Bettencourt, C., Garret-Gloanec, N., Pellerin, H., Péré, M., Squillante, M., Roos-Weil, F., ... & Cohen, D.Promoting emotional and behavioral interventions in ASD treatment: E v i d e n c e from EPIGRAM, a naturalistic, prospective and longitudinal study (submitted)

# *Introduction*

In recent years, the field of Information Communication Technologies (ICTs) has significantly increased in the care of individuals with Neurodevelopmental Disorders (NDD), notably Autism Spectrum Disorder (ASD). These tools, including serious games and apps, socially assistive robots, video modeling, and augmentative and alternative communication devices, have created new approaches to therapeutic and educational interventions. These digital technologies have been suggested in studies as effective tools to teach autistic individuals social and communication skills. ASD is characterized by difficulties in social interaction and communication, presenting unique challenges in their care. Interestingly, many studies have highlighted that autistic children often exhibit a natural affinity for technology and a good disposition for using and learning through the use of digital tools. This inclination may stem from the predictability and structure that ICTs provide. That is because the environment and context that these experiences provide are predictable and structured, which helps autistic children to maintain their routines and repetitive behaviors without affecting their comfort. Notably, socially assistive robots and games leveraging technology, including serious games, gamification, and e-learning, are particularly effective for teaching conceptual knowledge and communication and social skills to autistic children.

The increasing number of studies examining the effectiveness of these digital tools in therapy and education setting has arisen the critical need to assess their design features and research methodologies to accurately determine their efficacy and ways to improve their design adapted to the heterogeneous profiles of autistic children.

# *Chapter 1: Clinical Perspective*

## *Neurodevelopmental Disorders (NDD)*

Neurodevelopmental Disorders (NDD) are characterized by early-onset deficits of variable severity in personal, social, academic, or occupational functioning (APA, 2013). The term "neurodevelopmental" is used for a wide range of neurological and psychiatric disabilities that involve disruption in brain development (Thapar & Rutter, 2015). NDD include Autism Spectrum Disorder (ASD), Intellectual Disability, Communication Disorders, Attention Deficit Hyperactivity Disorder (ADHD), Specific Learning Disorders, and Motor Disorders (APA, 2013). These disorders share common features of developmental delays and deficits that impact various aspects of cognitive, social, emotional, language, motor functioning, executive functioning, and autonomy (APA, 2013). One of the main features of these NDD is that they usually begin during childhood, before puberty, and they are more prevalent in males (Thapar & Rutter, 2015). The severity of NDD can vary significantly, ranging from mild to severe delays or impairments. Some occur early before three years of three (e.g. Autism Spectrum Disorder (ASD); Intellectual Disability (ID)), whereas others only appear later (e.g., Tourette syndrome) or when exposed to learning at school (e.g., Specific Learning Disorder (SLD)). It is not uncommon for individuals with NDD to have multiple co-occurring disorders, resulting in complex and multidimensional impairments (Xavier & Cohen, 2020). To facilitate accurate diagnosis and understanding of these disorders, the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) provides a standardized framework. This diagnostic tool enables clinicians to identify and assess the symptoms of NDD, leading to more informed treatment decisions. By recognizing the distinct features and diagnostic criteria outlined in the DSM-5, clinicians can have a comprehensive understanding of NDD (Thapar & Rutter, 2015). This understanding is crucial for designing personalized interventions and support strategies tailored to the unique needs of individuals with NDD.

**Table 1. Current state of knowledge on the prevalence of neurodevelopmental disorders in childhood according to the DSM-5 (Francés et al., 2022)**

| **Neurodevelopmental Disorders** | **Worldwide Prevalence** |
|---|---|
| Autism Spectrum Disorder (ASD) | 0.70–3% |
| Intellectual Disability (ID) | 0.63% |
| Attention-Deficit/Hyperactivity Disorder (ADHD) | 5–11% |
| Communication Disorders (CDs) | 1–3.42% |
| Specific Learning Disorder (SLD) | 3–10% |
| Motor Disorders (MDs) | 0.76–17% |

There is growing evidence that NDD stem from a complex interplay of genetic and epigenetic factors (Bale et al., 2010; Rangasamy et al., 2013). Genetic predisposition plays a significant role, and certain inherited gene mutations or variations can increase susceptibility to develop a NDD. The high recurrence of autistic siblings supports the presence of heritable variants among multiplex families (Sandin et al., 2014). The largest population-based twin study of child neuropsychiatric disorders (N= 17000 children) confirmed the high heritability for ASD estimated at 80%, 79% for ADHD and 70% for motor coordination disorders (Lichtenstein et al., 2010). However, it appears that genetic vulnerability combines a mixed of rare major genes with strong causal value and common variants with low causal value even within multiplex families (Cirnigliaroa et al., 2023). Additionally, most cases of ASD caused by major genetic variants occur after de novo mutation, meaning without heritability. The role of gender in the disorders' vulnerability has not been well examined, despite of the higher prevalence of NDD in males (Sandin et al., 2013). Furthermore, perinatal influences, like maternal stress, exposure to toxins, and nutrition have been likely linked to the offspring of the disorders (Kolevzon, Gross & Reichenberg, 2007). Epigenetic factors, which involve modifications

to gene expression without altering the DNA sequence, attributing an important role to the environment, have also been linked to the disorder (LaSalle, Vallero & Mithcell, 2013). Research on motor coordination disorder has connected epigenetics to the heritability of the disorder. Notably, studies have shown the involvement of both genetic and shared environmental factors in the familial clustering of tic disorder in childhood (Ooki, 2005; Bolton et al, 2007). In contrast, in their epidemiological study Lichtenstein et al. (2010) did not find shared environmental effects for tic disorder. Environmental influences during critical developmental periods can lead to epigenetic changes that impact brain development, potentially increasing the likelihood of NDD (Sandin et al., 2013). Finally, environmental factors can also cause NDD. They include a large list of environmental injuries that will affect fetuses' or infants' brain development such as toxins (e.g. valproate during pregnancy), viral infections measles during pregnancy; infant's herpes virus encephalopathy), premature birth, neonatal anoxia (Guinchat et al., 2012). Understanding and identifying these complex causes is crucial for early intervention and effective management of these disorders.

# *Autism Spectrum Disorder: Overview Epidemiology*

Autism Spectrum Disorder (ASD) is a complex heterogeneous NDD that manifests in early childhood. ASD is characterized by persistent deficits in social interactions and communication across multiple contexts associated with restricted, repetitive patterns of behaviors and interests or hypo/hyper-reactivity to sensory stimuli (APA, 2015). ASD is a highly heritable and a heterogeneous disorder that has underlying cognitive features and commonly co-occurs with other conditions (Lord et al., 2020). ASD comorbidity is significant and can impact occupational, academic, autonomy, and other important areas of functioning. According to the World Health Organization (2023), it is estimated that 1 in 100 children meet the diagnostic criteria for ASD. However, the largest WHO study reported prevalence rates of 0.33% worldwide, with significant differences according to countries and socioeconomic indexes (Figure 1, Solmi et al., 2022). In France, the prevalence of ASD (all spectrum) is estimated between 0.9 and 1.2%, but the largest epidemiological study to date found a prevalence at 8 years of age of ASD with a significant handicap at 0.35% in Isère and Haute Garonne districts (Delobel et al., 2015). Over time, the reported incidence of ASD in children has risen, prompting questions from primary care providers about the underlying causes. Hyman et al., (2020) attributed the increase in prevalence to several factors, including the broadening of diagnostic criteria through successive revisions of the DSM, heightened public awareness of the disorder along with screening recommendations, and improved access to early intervention and school-based services. The emergence of ASD symptoms begins around 12 months of age and becomes more pronounced by 18 months of age, although a definitive diagnosis is often made at 3 years of age (Georgiades et al., 2013). From 12 months, observable markers of ASD start to appear, such as reduced eye contact, decreased vocalization towards others, decreased smiling, and a lack of response to their name (Werner et al., 2005). Affect expression also becomes poorer during this period (Zwaigenbaum et al., 2005; Mitchell, Cardy, Zwaigenbaum, 2011). Attention flexibility and stereotyped behaviors of exploration and object use show differences from 12 months as well (Zwaigenbaum et al., 2005).

Children at risk for ASD exhibit less functional play and more nonfunctional and repetitive play compared to typically developing children (Christensen et al., 2010). Early signs of atypical restricted and stereotyped behaviors are observed in children with ASD from 12 months (Wolff et al., 2014). Differences in gaze orientation and visual exploration of objects can also be detected at an early age, with some studies showing differences as early as 9 months (Zwaigenbaum et al., 2005). ASD is prevalent and can be diagnosed as early as 18 months. It is crucial for primary care providers to possess knowledge on the diagnostic criteria for ASD, as well as conduct accurate etiologic evaluations, and address any coexisting medical and behavioral issues (including sleep and feeding disorders, gastrointestinal symptoms, obesity, seizures, attention-deficit/hyperactivity disorder, anxiety, and wandering) that may interfere with the child's well-being and functional abilities (Hyman et al., 2020).The emergence of observable behavioral signs of ASD typically occurs after the first six months of a child's life (Zwaigenbaum et al., 2005). This delay in the manifestation of ASD related behaviors could be attributed to several factors. First, the social behaviors affected by ASD may not become evident until around 12 months of age (Langlois, Roggman & Rieser Danner, 1990). At this stage, typically developing children begin to display more pronounced social interactions and communication skills, which are significantly impacted in individuals with ASD. The absence of these behaviors in the early months can make it challenging to identify potential signs of ASD.

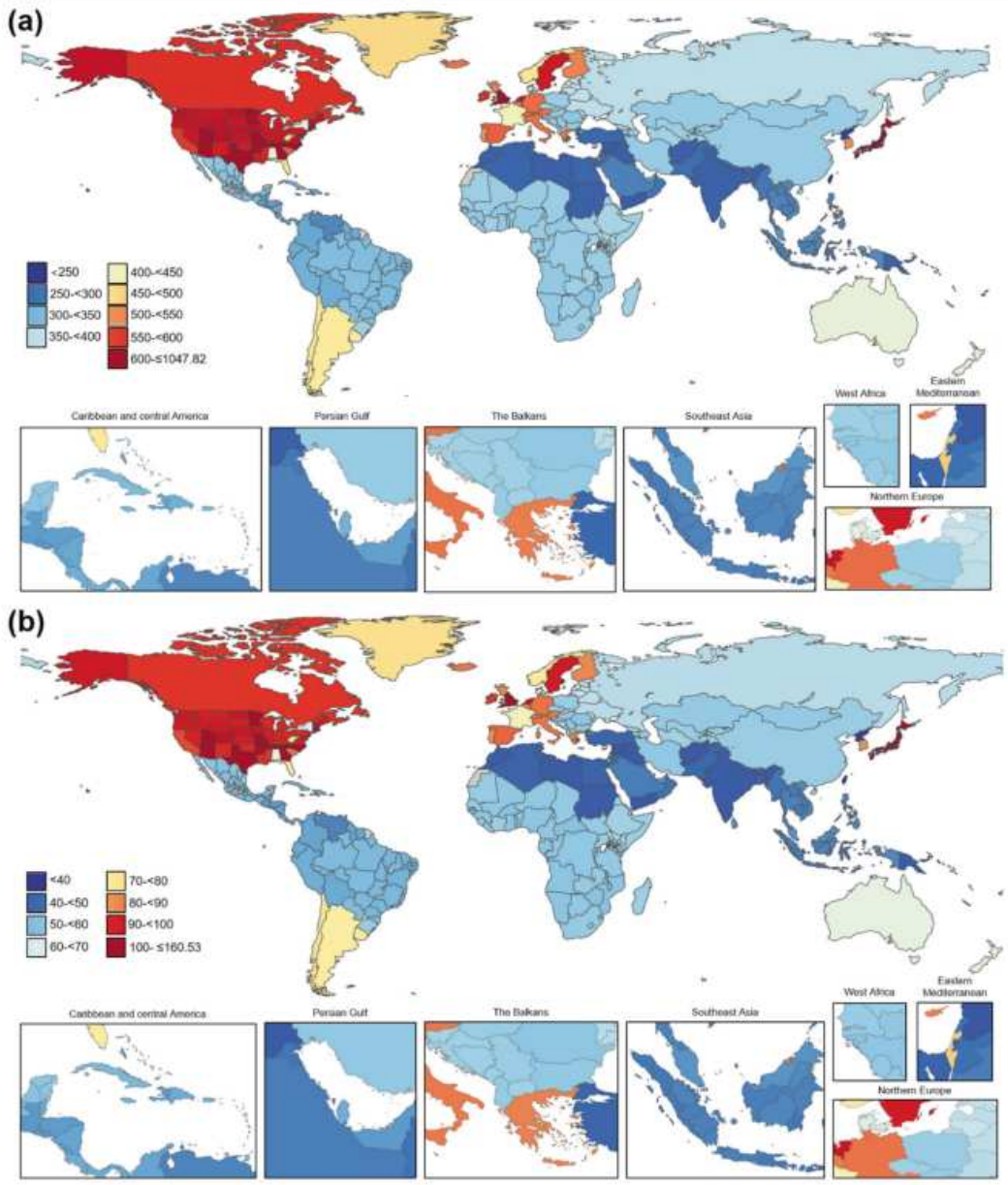


**Figure 1. Global burden of Autism-Spectrum Disorder by country or territory, 2019. (a) Age-standardized prevalence rates (per 100,000) by location, both sexes combined, 2019 (b) Age-standardized DALY rates (per 100,000) by location, both sexes combined, 2019. DALY disability/adjusted life-year (Solmi et al., 2022).**

Additionally, certain behaviors that may later be associated with ASD can initially be perceived as typical or age-appropriate during infancy. These behaviors only become concerning or pathological if they persist beyond the expected developmental timeline. For example, certain repetitive behaviors commonly observed in young children, such as repetitive hand movements or body rocking, may not be initially recognized as stereotypies until later in development (McCarty & Frye, 2020). Though the clinical signs that allow the diagnosis of ASD, such as communication deficits and restricted interests, are not present before 18 months, there are indications that certain characteristics may already be present in a different form (Elsabbagh et al., 2010). The search for signs moves towards identifying risk factors rather than the specific diagnostic criteria (Elsabbagh et al., 2010; Gliga et al., 2014). It is important to note that the absence of early observable signs does not imply the absence of ASD. As ASD manifests itself in early childhood, early diagnosis and intervention may considerably improve the quality of life of children with ASD and their families (Narzisi et al., 2014).

However, there are a number of challenges in terms of early identification and treatment. First, it is in part due to the lack of available biomarkers, accurate and timely diagnoses for children with ASD are a challenge for many health care systems (Pickles et al., 2020). Second, due to the heterogeneity of the disorder, children with ASD show differences both in social and cognitive functions, thereby necessitating different and adapted interventions tailored to the profile of the child (Warren et al., 2011). Third, it is problematic for parents to choose the most appropriate and effective interventions for their children, in addition to the challenges they face navigating the healthcare system (Salomone et al., 2016). It is through comprehensive developmental monitoring and regular assessments that healthcare professionals can identify the onset of ASD-related behaviors and intervene accordingly (Lord et al., 2020).

In this context, the French government launched the fourth autism plan in 2018 with the aim of improving the overall care of autistic patients. It is based in particular on the good practice recommendations of the HAS (2012). Early intervention is therefore at the heart of this project. Its objective is to promote diagnosis as early as possible and intensive therapeutic support from the first years of the child's life. To this end, it recommends in particular the greater involvement of families.

*Therapeutic Approaches*

Autistic children show differences both in social and cognitive aspects, thereby necessitating different interventions tailored to individual profiles (Vivanti et al., 2014). Narzisi et al (2014) summarized the common components of intervention models for autistic children that appear to be linked to greater therapeutic outcomes. They find that (i) early intervention, which includes both making an early diagnosis and minimizing the time between that diagnosis and treatment; (ii) intensity; (iii) family oriented; and (iv) regular assessments, updates on treatment goals and therapeutic supervision. They also find that most first intervention methods are aimed at developing communication prerequisites such as joint attention, imitation and symbolic play. Indeed, the development of these prerequisites is an important issue in the care of autistic children. The HAS also provided a set of recommendations with some level of evidence of effectiveness, consistent with the observations of Narzisi et al. (2014). It advocates a global intervention aiming to improve several skills: imitation, language, communication, play, social interactions, motor organization and action planning, daily life adaptive behaviors (HAS, 2012). The intervention must be regularly evaluated in order to review and adapt to the objectives. In addition, the inclusion of parents in the therapeutic project is essential so they can accompany their child at home and thus allow the transfer of skills to daily life.

A recent meta-review indicated that there was suggestive evidence for the effectiveness of various interventions such as early intensive behavioral interventions, developmental interventions, naturalistic developmental behavioral interventions, and parent- mediated interventions in preschool children (Gosling et al., 2022). These interventions have led to their widespread adoption in clinical practice, e.g., Naturalistic Developmental Behavioral Interventions (NDBI) (Gosling et al., 2022), notably, early intensive behavioral intervention (EIBI) (Rattaz et al., 2020), the Early Start Denver Model (ESDM) (Dawson et al., 2010), the Exchange and Development Therapy (Blanc et al., 2013) and Joint Attention Symbolic Play Engagement and Regulation (JASPER) (Goods et al., 2013).

Treatment for autistic children should also include parent-mediated interventions (e.g., The Preschool Autism Communication Trial - PACT (Pickles et al., 2016). These have been initially included in the Treatment and Education of Autistic and Communication Related Handicapped Children (TEACCH) program, which has shown minor effects in meta-analyses (Virues-Ortega et al., 2013). Furthermore, educational interventions and specific therapies (e.g.,

speech therapy, occupational therapy, psychotherapy) can also be found in ASD care (Narzisi et al., 2014). These interventions showed positive effects on outcomes including social communication deficits, global cognitive abilities and adaptive behaviors. Additionally, results strongly suggested that parent-mediated interventions led to improvements in disruptive behaviors among early school-aged children. The effectiveness of social skills groups was also suggested to improve social communication deficits and overall ASD symptoms in school-aged children and adolescents. Notably, only four meta-analyses demonstrated statistically significant pooled effect sizes in a sensitivity analysis that focused on randomized controlled trials with low risk of detection bias. Table 2 summarizes the main interventions and the level of evidence supporting them (from Gosling et al., 2022).

Naturalistic developmental behavioral interventions (NDBIs) could be the most promising interventions according to a recent therapeutic review taking into account the study's methodology quality (Sandbank et al., 2020). Indeed, one of the first intervention that was proven to be effective in a randomized controlled study (Dawson et al, 2010), was ESDM. The authors observed "improvements in intellectual quotient, language, adaptive behavior, and brain function" in autistic children who received this intervention (Dawson et al, 2010). However, Gosling et al., (2022) revealed in their random-effects meta-analysis that ESDM efficacy was supported by weak evidence, a statistically significant but small-pooled effect size (SMD = 0.22, p-value = 0.02). We briefly describe here ESDM as it has inspired GOLIAH a serious game that will be detailed in chapter 6. This early intervention program was developed for autistic children from 12 to 48 months and is grounded on a developmental approach with positive reinforcement. It is based on two theoretical hypotheses (Schröder et al., 2015): on the one hand, the studies of Daniel N. Stern (1991) assumes that autism is linked to "an early imitation disorder", and on the other hand those of G. Dawson and C. Chevallier which hypothesize "a lack of social motivation" (Dawson et al., 2005; Chevallier et al., 2012). The ESDM is based on an important work of social interactions through ritualized game-based situations that can then be transferred to the ecological environment. The goal is to reduce the severity of autism-related disorders and to accelerate the pace of development in all areas: imitation, joint attention, communication, language, and the desire to join others and play. Among the precursors of communication, social skills such as imitation and joint attention are particularly important to develop. Clinicians regularly assess the child's progress in order to tailor goals to ensure personalized intensive

therapy (Schröder et al, 2015). In addition, parental participation especially at home is essential in the context of this method to allow intensive rehabilitation (the HAS recommends between 20 and 25 hours of weekly training).

**Table 2. Overview of therapeutic approach in autism: evidence according to symptom targets (*Gosling et al. Mol Psy 2022)***

| Method | Age (years old) | ↘ overall ASD symptoms | ↗ social communication | ↘ repetitive/ restricted symptoms | ↗ expressive language | ↗ receptive language | ↗ adaptative behaviors | ↗ overall cognition | ↘ disruptive behaviors |
|---|---|---|---|---|---|---|---|---|---|
| Early Intensive Behavioral Intervention | < 6 | ns | Suggestive | | Weak | Weak | Suggestive | Suggestive | ns |
| Developmental Intervention | < 6 | Weak | Suggestive | | ns | ns | | | |
| Naturalistic Behavioral Developmental Intervention | < 6 | ns | Suggestive | ns | Weak | ns | ns | Weak | ns |
| Social Skills Group | > 6 | Suggestive | Suggestive | Weak | | | | | ns |
| Cognitive Behavior Therapy | > 6 | | Weak | | | | | | |
| TEACCH | < 6 | | ns | | ns | ns | ns | Weak | |
| Parent Mediated Intervention | < 6 | Weak | Suggestive | | ns | ns | ns | Weak | Highly suggestive |
| Techonology Mediated Intervention | Various | | Weak (>6) ns (>6) | | ns | ns | Weak (13-19) | | ns |

*TEACCH*= Treatment and Education of Autistic and related Communication-handicapped Children; ns= not suggestive

From a broader view, the treatment that can be offered to children with ASD depends on both macro- and micro-variables. Macro-variables include the healthcare system, the financial support available for low-income families, and the school system's openness to accommodating children with special educational needs. Micro-variables include the socio-economic background, migrant status, time of diagnosis, and severity of any comorbid intellectual disability (ID) (Salomone et al., 2020; Hyman et al., 2020). Salomone et al. (2016) found that a varied implementation of intervention is observed throughout Europe, considering both the type of intervention and the quantity received. Additionally, the study revealed a correlation between the use of intervention and both the educational level of parents and the characteristics of the child. For example, in France, day care hospital from free public services provide care of autistic individuals that come from low-income and/or migrant families more often. Autistic patients from migrant families exhibit more severe autism and more frequent challenging behaviors (Bettencourt et al., 2022). Furthermore, due to the disorder's heterogeneity and symptoms variability, there is no single best approach. What works well for one child in therapy may not be effective for another due to the diversity in their experiences (Cabibihan et al., 2013).

## *Specific interests related to this thesis Social Skills Deficits as the Core of ASD*

The origin of social skills deficits in ASD has been the subject of several theories. Baron-Cohen (1995), in particular, uses his modular model of the development of the theory of mind to explain the cause of these difficulties. Indeed, some stages of this model would be deficient in autistic patients. The first two modules, the intentionality detector and the eye direction detector, would not be impacted in the context of ASD. Thus, autistic individuals would be able to understand that others have purpose-oriented mental states and to detect and interpret the presence and direction of others' gaze. On the other hand, their system of shared attention that allows coordinated joint attention would be in deficit. Thus, their theory of mind would be deficient which would explain the difficulties faced by autistic children in terms of social skills.

A second theory is that these difficulties are caused by a lack of early social motivation. Dawson (2005) explained that autistic individuals would be less influenced by social reward marks and thus less attentive to certain social signals. As a result, autistic individuals would be less likely to initiate and maintain interactions and thus less exposed to social learning situations. This lack of social attention could increase their difficulties in developing the prerequisites for communication (joint attention, imitation, etc.) (Chevallier et al., 2012). Chevallier (2012) presupposes that this lack of motivation would have effects upstream of the acquisition of social cognitive abilities.

Social skills acquisitions are necessary for the development of more complex social skills (Tomasello, 2005). ASD can have a significant impact on the educational and socio- professional integration of patients. Enabling autistic children to develop their social skills from an early age is therefore a major challenge for their empowerment. Gosling et al. (2022) recommend specific work to improve autistic children’s social interactions. The goal of social skills training is to improve communication, expression of feelings and interactions, by transmitting interpersonal skills to patients and promoting their generalization and maintenance (Baghdadli, 2011). Several studies have shown the effectiveness of social skill groups in autistic children for this type of rehabilitation (Bohlander et al., 2012). These include a reduction in inappropriate behavior and the emergence of socially desirable behaviors (Andanson, 2011). In addition, through these groups, autistic children develop conversational (initiation, maintenance and closure of the

exchange) and emotional skills such as perceiving and understanding an emotion (Kruck et al., 2017).

*Social Skills Group Interventions*

Group-based psychosocial skills interventions are widely employed to enhance social skills in autistic youth (Gates et al., 2017; Reichow, Steiner, & Volkmar, 2012). However, despite their widespread use, the effectiveness of these interventions remains uncertain due to an absence of rigorous and well-designed research (Reichow, Steiner, & Volkmar, 2012; McMahon et al., 2013), and a lack of complete and sensible psychometric tests to effectively measure social skills in their entirety (Wigelsworth et al., 2010). The inconclusive findings can be attributed to several factors, including the absence of a universally accepted definition of social skills, variations in adapted scales, and differences in the implementation of therapeutic approaches, particularly in terms of treatment intensity and duration (Rao et al., 2008). Group interventions provide a social context that reflects real-world situations, allowing autistic children to practice and generalize their social skills in a supportive and inclusive environment. By engaging with peers who may share similar experiences and challenges, children with ASD have the opportunity to learn and observe appropriate social behaviors, communication techniques, and social cues (Bellini, 2008). This social exposure and interaction help them develop a better understanding of social norms, fostering improved social competence and reducing social isolation (Gates et al., 2017).

Furthermore, group interventions offer a unique platform for social learning and peer modeling. Autistic children often struggle with social reciprocity and understanding social cues, making it challenging for them to acquire social skills through typical observation and imitation processes (Bauminger et al., 2007). In a group setting, these children can observe and learn from their peers who demonstrate appropriate social behaviors. This peer modeling allows for the acquisition of new social skills, as well as the opportunity to practice and receive feedback in a supportive and non-judgmental environment (Reichow, Steiner, & Volkmar, 2012).

Additionally, group interventions facilitate the development of crucial social interaction skills, such as turn taking, active listening, and perspective taking. Through structured activities and group discussions, autistic children learn how to engage in reciprocal conversations, share experiences, and empathize with others (Reichow, Steiner, & Volkmar, 2012). These interventions often incorporate evidence-based strategies, such as social stories, visual supports,

and video modeling, to enhance learning and comprehension of social concepts (Bellini, 2008). The success of group-based interventions for autistic children is also attributed to the supportive and inclusive environment they create. Within these groups, children can form connections with their peers, fostering a sense of belonging and acceptance. This positive social environment promotes self-esteem, confidence, and motivation to engage in social interactions (Reichow, Steiner, & Volkmar, 2012).

Nevertheless, a recent meta-review provides suggestive evidence supporting the efficacy of social skills groups (SSGs) in improving social communication deficits and overall symptoms associated with Autism Spectrum Disorder (ASD) in school-aged children and adolescents (Table 2, Gosling et al., 2022). This indicates that despite the challenges and inconsistencies in research methodology and implementation, SSGs have demonstrated promising outcomes for addressing social difficulties in individuals with ASD. Interactive play is a major key in interventions of young autistic children as it addresses the core deficits of relating and communicating with others (Greenspan & Wider, 2006).

*The role of Play in ASD care*

Play is crucial in the development of children, including those with atypical development. Autistic children often exhibit unique characteristics in their approach to play, with a preference for sensorimotor activities over symbolic play compared to neurotypical children (Blanc et al., 2005). These differences in play behavior can have a significant impact on the child's development and their relationships with their families (Perrin, 2011). By recognizing the importance of play, it becomes essential to incorporate play-based interventions in ASD care. Perrin (2011) suggests that play can serve as a valuable medium for developing communication and social skills in autistic children. The social interactions that arise during play naturally foster essential communication precursors such as joint attention, imitation, and symbolic play (Perrin, 2011). Through play, children can learn to understand concepts like yes/no answers, waiting times, transition times, requesting help, and following instructions (Donard & Simar, 2012). Several intervention models for autistic children, such as the Early Start Denver Model (ESDM), rely on play as a fundamental component (Dawson et al, 2010).

In addition to traditional forms of play, video games have drawn attention from researchers in the field. Donard and Simar (2012) highlight the potential of video games as a

promising tool for supporting the care of autistic children. Video games provide a visually engaging and playful platform that can be used to intensively train deficit skills. Moreover, video games designed to promote shared experiences and social interaction, can act as mediators for developing joint attention and imitation skills. However, adapting commercial video games for therapy sessions can be challenging, leading researchers to advocate for the use of serious games specifically designed for therapeutic purposes. The use of virtual worlds in therapy has also been explored, particularly with autistic adolescents (Strickland, 1997). Virtual worlds offer a unique opportunity to represent and explore complex emotions and fears that may otherwise be difficult to articulate (Maskey et al., 2019). Avatars within virtual worlds can serve as extensions of oneself, characters from personal experiences or stories, or even embodiments of familial or ancestral legends. This immersive and symbolic environment allows individuals to engage with their inner world in a safe and controlled manner (Strickland, 1997). Play-based interventions can facilitate the development of communication and social skills in autistic children (Greenspan & Wider, 2006).

Additionally, the use of video games, particularly serious games, shows promise in supporting therapeutic interventions for autistic children (Grossard et al., 2018). By leveraging these play-based approaches, therapists and caregivers can enhance the well-being and development of individuals with ASD.

# *Chapter 2: Engineering Perspective:*

## *Information and Communication Technologies (ICTs) in NDD and ASD Care*

### Introduction

The use of Information and Communication Technologies (ICTs) has gained significant attention in the field of NDD, particularly in ASD research and care (Grynszpan et al., 2014; Hollis et al., 2017; Miguel Cruz et al., 2017; Khan et al., 2019; Grossard et al., 2018). Over the past two decades, the integration of ICTs, including social robots, serious games, video modeling, and augmentative alternative communication devices, has transformed the approach to therapeutic and educational interventions for individuals with NDD (Grossard et al., 2018). These technological advancements have provided clinicians and individuals with NDD with new opportunities to enhance social and communication skills (Light, McNaughton, & Caron, 2019), cognitive functioning (Tseng et al., 2020), and overall quality of life (Grossard et al., 2018).

These digital therapeutic tools can be implemented on many types of supports, including computers, tablets, smartphones, screen projectors, wearable technologies such as virtual reality headsets or smart watches and robots. They can take multiple forms as apps, serious games, assistive technologies, and immersive reality (Grossard et al., 2023). These tools can target a wide range of skills or behaviors as social and communication skills, academic knowledge, sensory and motor skills, autonomy and inclusion, emotion regulation (Grynszpan et al., 2014; Boucenna et al., 2014; Valentine et al., 2020). They can be used in diverse settings including care centers or hospitals, schools or homes (Miguel Cruz et al., 2017, Khan et al., 2019). ICTs are generally well accepted by parents and professionals but also by children or adolescents with NDD (Valentine et al., 2020; Richardson et al., 2018). However, a few numbers of studies have targeted adult users (Valentine et al., 2020).

The growing increase of numerical tools application in NDD care created a crucial need to assess the design of ICTs and the research methodology quality used to evaluate them (Grossard et al., 2023). Moreover, the absence of standard framework to assess ICTs design influenced the creation of the first Design ICT Inventory (DICTI, Grossard et al., 2023), a tool aiming to support ICT developers when creating therapeutic digital tools for NDD people. While

the application of ICTs in NDD care is promising, there are some challenges that need to be addressed, particularly in regards to the poor methodological quality of studies and optimizing the design of these technologies (Grossard et al., 2023). The need for high- quality studies and user-friendly and affordable ICTs is evident, as current research lacks consensus on intervention duration, intensity, and user support requirements (Zervogianni et al., 2020; Miguel Cruz et al., 2017; Hollis et al., 2017; Moon et al., 2020).

## *Socially Assistive Robots in ASD Care*

In recent decades, robotics have become firmly embedded in the field of healthcare in various disciplines, elevating medicine and providing relief to people with countless conditions (Grossard, et al., 2018). These robotic interfaces have essential features like communicating with people, understanding social, organizational, and physical situations through sensed data, supporting individuals with special needs, improving elderly healthcare, and aiding in learning and rehabilitation during daily tasks (Esposito et al., 2014). In the past ten years, significant research has been conducted in regards to robotics and autism, creating an emerging field of study that is only gaining momentum. Currently, there are many robots on the market that claim to help children with autism spectrum disorder (ASD) to develop learning and social skills, a claim that could radically change autism research (Pennisi et al., 2016). While this research is vast, it is also limited by scope, time, and resources, showing that more meaningful data needs to be collected in order to fully understand how robots can help autistic children in both the short and long-term.

Numerous studies have been conducted that explore how robots may positively impact detection and intervention methods for autistic children (Cabibihan et al., 2013). Having social robots to take the place of educators when applicable can alleviate a significant pressure from the already over-burdened educational system and parental involvement, while simultaneously ensuring that autistic children get the support they need to encourage development. There is rising evidence, which supports that autistic children have unique opportunities to use robots for therapeutic purposes (Cifuentes et al., 2020, Kumazaki et al., 2020, Grossard et al., 2018 & Scassellati et al., 2007). Contrarily to human interactions, robots' predictability provides a highly structured and learning-driven environment to autistic individuals. These types of interactions

with humanoid robots are likely to form consistent social situations in which certain social behaviors can occur (Kumazaki et al., 2020 & Scassellati et al., 2007). Robots' design characteristics and functionalities can play a significant role in the efficacy of the therapeutic intervention (Cabibihan et al., 2013).

The goal of this literature review is to explore recent literature regarding how these robots interact with and elicit progress and can positively impact autistic children both in the short- term and long-term, as well as navigate current and potential limitations of these studies and their implications. Table 3 offers a brief overview.

## Characteristics of the robots

In the past decade, significant strides have been made to unite gaming and robotic technology with teaching autistic children, resulting in an emerging field of socially assistive robotics (Grossard, et al., 2018). While some of the robots take on the form of the traditional, non-anthropomorphic shapes, including the Nao, Riby, QT Robot, IRobiQ, Caro, and Kibo, others take on human-like or animal-like characteristics, including Kaspar, Charlie, R 50 Alice "Mina", and KiliRo. The robots' embodiment includes android, human-like, animal- shaped, non-anthropomorphic colored toys: in any case, the shape of the robot should contribute to the reduction of the stress of the children during the experiment, making them comfortable and at ease (Ahmad et al., 2019). The uncanny valley concept has been widely used in robot's design. It refers to the phenomenon where a robot's resemblance to a human becomes almost too realistic, creating a sense of discomfort in human observers (Bartneck et al., 2009). When a robot is very close to appearing human but still presents minor differences, notably in its movement, the social meaning associated to it can lead to unease (Bartneck et al., 2009). This concept works in robot design because it emphasized the importance of achieving a balance between human likeness and avoiding the unsettling effect of the uncanny valley, guiding designers to create robots that evoke positive and relatable emotions.

Essentially, while autistic children generally have difficulty interacting and socializing with other humans, interacting with autonomous robots may remove the pressure associated with people, leaving the child less stressed and able to focus on other things (Bharatharaj et al., 2017). Understanding the individual needs of an autistic child is vital in assessing which robot may be right for them. However, as some may be less inclined to interact with a humanoid-robot like Kaspar, for example, due to the robot's uncanny qualities; there is no one-size-fits-all approach. It is also important to note that while these robots are impressive, they are also relatively new, and continue to undergo significant changes in their physical appearance as well as their programming (Albo-Canals et al., 2018).

**Table 3. Main robots used with autistic individuals**

| Robots | Description | Targeted skills | Relevant studies |
|---|---|---|---|
| Nao  | 50 cm tall<br>25 degrees of freedom<br>2 cameras<br>Microphones<br>Speakers<br>Touch sensors<br>LEDS<br>Sonars<br>WIFI and Ethernet connection<br>Software allows personalization<br>Can be used in classroom, hospital, etc. | Joint attention<br>Imitation<br>Turn taking<br>Eye-contact<br>Pointing<br>Basic academic skills<br>Facial expressions<br>Verbal communication<br>Improve spontaneous social interaction<br>Improve robot responses to children's affective state and engagement. | In Chevalier et al. (2016), authors explored the relationship between perceptive-cognitive and sensorimotor abilities of participants with their ability to positively engage with the Nao robot. They found that those participants with strong visual dependency had more success interacting with the Nao robot than the participants with stronger proprioception integration. |
| TEO4  | 80 cm tall<br>2.5 h autonomy<br>Possibility to stick different faces magnetically<br>Dedicated to children with ASD<br>Distance sensors<br>Touch sensors<br>1 camera<br>Autonomous reactions but can also be drive by an operation<br>Can move and speak. | Social skills, positive emotions, self expression. | Bonarini et al. (2016) recorded 11 children with ASD engaging with free-play with the robot TEO4 over a course of 43 sessions of approximately 12 minutes each. They found generally positive trends in terms of communication with, manipulation of the robot, externalization of need, positive emotion, creativity, and body stereotypes. |

| | | | |
|---|---|---|---|
| Riby<br>  | 130 cm tall<br>Sonar sensors | Engaging interaction | Romero et al. (2017) described the process through which they developed the Riby robot, a robotic tool for use in treatment of ASD in adults.<br>The Riby robot design appears conducive to ASD intervention in adults, but ongoing research is needed to continue its evolution. |
| R 50 Alice<br>"Mina"<br>  | 69 cm tall<br>32 degrees of freedom with 11 degrees of freedom in the head of which 9 are for facial expression and 3 are for neck movements<br>Speaker | Facial expression production<br>Facial expression recognition<br>Imitation | Taheri et al. (2018) observed how three pairs of autistic children, including twins, siblings, and classmates, engaged in individual/group imitation and joint imitation tasks with the "Mina" robot.<br>Different assessment tools, including the GARS and ASSP questionnaires, were used to gauge improvement both during the HRI and outside with external interactions. All participants improved their visual attention, verbal and nonverbal communication, and joint attention, regardless of where they were in terms of pairing. |
| QT Robot<br>  | Screen as face<br>14 degrees of freedom for upper-body gestures<br>3D camera<br>1 microphone<br>Connection by WI-FI | Training emotional abilities<br>Body language<br>Increasing the efficiency of therapy by encouraging an active and engaged interaction | Costa et al. (2018) examined how fifteen children with ASD interact with people vs. the QT robot in two separate interactions to measure levels of engagement through eye contact.<br>The participants gazed at the person in more instances. However, they gazed longer at the QT robot when they did look at it. |

| | | | |
|---|---|---|---|
| IRobiQ<br>  | 45 cm tall<br>Speakers<br>1 touch screen<br>Touch sensors<br>Sonars sensors<br>IR sensors<br>1 RGB camera in the head<br>LEDS | Training emotion abilities and interpersonal interaction | Yun et al. (2017) conducted a research in which four certified speech-language therapists utilized the IRobiQ as an intervention tool with four children with ASD over eight sessions. Both verbal and emotional expressions were gauged.<br>They found positive results, as each child was able to progress in their ability to initiate conversation with the robot as well as express emotions. |
| Caro<br>  | 93 cm tall<br>1 touch screen<br>Touch sensors<br>Depth camera<br>RGB camera<br>LEDS | Engage in emotional interplay and emotional recognition | Kostrubiec and Kruck (2020) developed and tested how the Caro robot could help 20 children with low-functioning ASD learning basic psychosocial skills through interacting with the robot.<br>They found that the ASD students displayed more positive responsiveness and physical orientation towards the robot than the human teachers. |
| KiliRo<br>  | Semiautonomous<br>2 degrees of freedom in each leg<br>Head can move down, up, right and left<br>Tail can move right and left<br>One speaker attached on the robot | Learning and social interaction abilities | Bharatharaj et al. (2018) observed how ten participants with ASD interacted with the KiliRo robot over the course of three sessions in comparison to interaction with other humans.<br>Results indicate that participants were more interactive with the robot than with humans in the 12 types of social engagement examined. |

| | | | |
|---|---|---|---|
| Kibo  | Programmable, add-on parts | Teaches coding and sequencing | Albo-Canals et al. (2018) conducted a research in which twelve participants were observed in a one-week period over a series of four sessions in which the robot worked towards helping them learn cause-and-effect.<br>Of the twelve participants with severe ASD, only two completed 80% or more of the sessions. Despite overall positive participants' engagement with the KIBO robot, more studies are necessary. |

***Identification of social cues during interaction***

One of the key areas of research regarding robots for autistic children is their capacity to identify signs when the child is in a state of acute stress, which is important because ASD symptoms are often exacerbated in stressful situations (Ismail et al., 2019). The Charlie, NAO, TEO4, and Riby robots can detect, through the use of specific algorithms, certain physiological signs like elevated voice, breathing, and heart rate that can predict when a autistic child may need a reduction in stimuli or other external intervention (Cifuentes et al., 2020; Romero et al., 2017). Additionally, some robots are adept at identifying and adapting to the individual difficulty levels that students need based on repeated exposure and data collection, making them an assistive technological tool that progresses alongside the child (Ismail et al., 2019). In the context of learning by imitation, robots where able to detect a social signature of autistic children through their motor behavior during motor imitation gaming (Boucenna et al., 2014).

***Intervention of the robots***

Studies show that one of the key ways in which a robot elicits improvement for autistic children is by promoting interaction between a child and another person, or what is known as social overture (Schadenberg et al., 2020). Robots will have different ways of eliciting this interaction, including using a screen, speakers, lights, being remotely operated by someone through Wi-Fi, etc. Specifically, the NAO, Kaspar, Riby, QT Robot, KiliRo, and Kibo Robots are designed to facilitate interaction from autistic children through a combination of social play scenarios, engaging and collaborative activities, and predictable actions (Cifuentes et al., 2020; Romero et al., 2017; Costa et al., 2018; Albo-Canals et al., 2018). In most cases, robots are not autonomous and controlled by an operator (i.e.: engineer, clinician, teacher or caretaker). Another goal of some of these robots is to facilitate standard modes of emotional expression, both in projecting normative expression and learning to interpret these expressions from others (Lecciso et al., 2021; Bharatharaj et al. 2017). Amongst the robots examined, the NAO, Kaspar, Charlie, Alice "Mina", QT Robot, IRobiQ, and CARO are designed to integrate emotional cues like facial expressions to facilitate imitation and understanding by autistic children (Cifuentes et al., 2020; "Kaspar", 2020; Romero et al., 2017; Taheri et al., 2018; Costa et

al., 2018; Ismail et al., 2019). A third goal of robots designed for autistic children is to improve their learning skills, including TEO4 and KiliRo, which assist in learning numbers, alphabets, and recognizing others (Romero et. al.; Bharatharaj et al., 2017).

Of the studies examined, results indicated that consistent, structured exposure to robots yielded positive outcomes. Specifically, areas of joint attention, emotional understanding, elevated interaction, and learning development indicated some progress for autistic students (Scassellati et al., 2018; Taheri et al. 2018). Due to the nature of ASD, however, these results were difficult to accurately measure for several reasons, including the fact that they were highly dependent upon the initial level of functioning expressed by the participants and study's methodology. Furthermore, higher quality research needs to be conducted in order to yield results that may change the approach towards autistic children; as of now, robotics are viewed as a potentially effective supplemental element that may help when used in conjunction with parental, educational, and therapeutic interventions. Short-duration robot-based interventions, typically consisting of about 8 sessions lasting approximately 30 minutes each, have shown potential in aiding social communication. These interventions have demonstrated meaningful improvements, at least immediately following the intervention period (Kouroupa et al., 2022) While the use of robotic assistants in therapy and education of autism children is still a relatively new field, it has shown promise in improving social interaction skills. As technology continues to advance, it is likely that robotic assistants will become increasingly integrated into autism intervention programs.

## *Serious Games in ASD Care*

Over the past decade, digital tools have been increasingly studied in the care of autistic children (Mazon, Fage & Sauzéon, 2018). New alternative developmental approaches based on play therapy are now being proposed, such as serious games. The number of studies regarding their use has rapidly increased in recent years (Grossard, Grynszpan, 2017). In his thesis in 2007, Alvarez proposes a definition of the serious game based on several theoretical approaches: "Computer application, whose objective is to combine both serious aspects (Serious) such as, non-exhaustively, teaching, learning, communication, or information, with ludic springs from the video game (Game). The

purpose of such an association is therefore to move away from simple entertainment." Thus, he explains that the serious game brings together two aspects: both "a video game scenario" and "a utilitarian scenario". The goal is to motivate the patient to perform the task by offering an attractive and pleasant game environment. The playfulness is a support for the patient to perform the task and improve their skills (Mélia, 2015).

In 2014, Grynszpan et al, conducted a meta-analysis that showed that serious games are an effective complementary tool in the management of autistic patients, particularly for the development of certain specifically targeted social skills (Grynszpan et al, 2014; Grossard et al, 2017; Cohen et al, 2017). In addition, a large portion of serious games for autistic children are aimed at improving social and communication skills (Spiel et al., 2019). Due to easy access and the possibility of home treatment, serious games have many advantages for the care of individual patients. Indeed, their accessibility allows to increase the exposure to the rehabilitative exercises and to make the rehabilitation more intensive (Flores et al, 2008; Freitas, et al, 2012).

On the other hand, digital media have the advantage of being particularly attractive to autistic patients. Digital media, moreover, allows for recurrent presentation of information and thus provide a safe play setting for the child (Knight et al., 2013; Mitchell et al., 2007). Feedback is instantaneous and can be anticipated (Moore, McGrath & Thorpe, 2000). The clarity of digital activities allows children to focus their attention specifically on the task at hand and decrease distracting stimuli (Moore et al., 2000). In addition, mobile technologies (smartphone and tablet) are particularly easy to use and suitable for everyday use (Mazon & Sauzéon, 2021). Furthermore, therapists with access to recorded digital data can assess patients' progress (Bono et al., 2016) remotely and customize the rehabilitation protocol as close as possible to each individual's skills, thus providing personalized training (Rego et al, 2010). The increasing availability of digital tools for individuals with NDD has raised the urgent need to effectively evaluate their benefits and costs (Miguel Cruz et al., 2017). The U.S. Food and Drug Administration (FDA) recently granted clearance for EndeavorRxTM, an Akili video game therapy designed for ADHD, marking it as the first prescription treatment delivered through a video game (Canady, 2020; Kollins et al., 2020). This innovative adaptation of serious games is exemplified by the transformation of Endeavour for Alzheimer's into Akili,

specifically tailored for children with ADHD. Akili utilizes the captivating nature of gaming to enhance attention, executive functioning, and cognitive skills. By building upon the successful framework of Endeavour for Alzheimer's, Akili provides a personalized solution that addresses the specific needs of children with ADHD, offering an interactive and enjoyable approach to support their cognitive development and overall well-being (Kollins et al., 2020).

# *Chapter 3: How can we assess and score the quality of the design of an ICT tool?*

This question was the subject of an article published in 2023:

Grossard, C., Bettencourt, C., Kellems, R., Chetouani, M., & Cohen, D. (2023). Building the design ICT inventory (DICTI): A Delphi study. *Computers in Human Behavior Reports*, *9*, 100261.

***Summary:***

The use of Information and Communication Technologies (ICTs) for individuals with Neurodevelopmental Disorders (NDD) has significantly increased over the last few decades. However, assessing the quality of these technologies is challenging due to a lack of consensus on their design. To address this, researchers used the Delphi method to create a trans-ICTs inventory called the Design ICT Inventory (DICTI). This inventory helps guide and evaluate the design of the four main ICTs implemented in NDD care: serious game/App, robotics, video modeling, and augmentative and alternative communication. After two rounds with feedback from 12 experts on ICTs and NDD, consensus was reached on 13 key items in the inventory, including customization, feedback, rewards, contextualized learning, motivation enhancement, difficulty management, accessibility improvement, clear instruction and content, attention capacity, clear goals, minimalistic graphics and audio, human interaction, and trustworthiness.

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# Building the design ICT inventory (DICTI): A Delphi study

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ABSTRACT

The use of Information and Communication Technologies (ICTs) for people with Neurodevelopmental Disorders (NDD) is increasing; however, it is currently hard to assess its quality as there are issues regarding the lack of consensus on how to design these technologies. Here, using a Delphi method, we built a *trans*-ICTs inventory named the Design ICT Inventory (DICTI) to guide and gauge design in the 4 main ICTs dedicated to people with NDD (serious game/App, robotics, video modeling, augmentative and alternative communication). After two rounds with feedback from 12 experts, we obtained consensus and agreement for each of the 13 items of the inventory: customization; feedback; rewards; contextualized learning; enhance motivation; manage difficulty; increasing accessibility; clarity of instruction and content; attention capacity; clear goals; minimalistic graphics and audio; human interaction; and trustworthy. The DICTI provides an easy tool to use in order to assess the design of ICTs. Future research is needed to ensure the inter-reliability of the inventory and its relevance in assessing ICT.

## 1. Introduction

Neurodevelopmental disorders (NDD) are a group of conditions characterized by delays in developmental domains such as social and communication skills, intellectual and executive functioning, motor skills and behavior (American Psychiatric Association, 2015). People with NDD may have mild to severe impairments in academic learning, social and personal functioning, and autonomy (American Psychiatric Association, 2015). According to the timing of the earliest clinical expression, they include intellectual disability (ID), Autism Spectrum Disorder (ASD), communication disorders (CD) that show first symptoms during infancy and toddlerhood, specific learning disorders (SLD), motor coordination disorders (MCD) and Attention Deficit/-Hyperactivity Disorder (ADHD) that usually start later during childhood (American Psychiatric Association, 2015). Such NDD are frequently combined with other NDD comorbidities, resulting in multidimensionally impaired children (Xavier & Cohen, 2020). The use of Information and Communication Technologies (ICTs) for people with NDD has increased over the last 20 years (Grossard et al., 2017). Many ICT supports are used with this population: computer, mobile devices like smartphone or tablet, screen, robots, or virtual and augmented reality. They can take multiple forms as serious games or apps, assistive technologies, or immersive reality. They can target a wide range of skills or behaviors such as social and communication skills, academic knowledge, sensory and motor skills, autonomy and inclusion, emotion recognition, production, or regulation (Boucenna et al., 2014; Grynszpan et al., 2014; Valentine et al., 2020). They can be used in diverse settings including care centers, schools, or at home (Khan et al., 2019; Miguel Cruz et al., 2017). ICTs are generally well accepted by parents and professionals but also by children or adolescents with NDD (Richardson et al., 2018; Valentine et al., 2020). However, few studies have targeted adult users (Valentine et al., 2020).

ICTs seem to be promising tools to help people with NDD in their daily life. However, it is important to remember that these results have to be taken with caution because of the methodological limitations of the studies conducted in the field (Grynszpan et al., 2014; Khan et al., 2019; Moon et al., 2020). There are many reasons that can explain the difficulty to assess ICT tools: (i) the poor quality of studies with small sample sizes (Khan et al., 2019; Moon et al., 2020), (ii) the lack of framework to guide the design in ICTs, resulting in an important heterogeneity among ICT tools (Carlier et al., 2020; Khowaja & Salim, 2020) and (iii) a large variety of methods to assess these technologies (Grossard et al., 2017;

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Whyte et al., 2015). Guidelines aiming to improve studies' methodology based on evidence-based approach are not sufficiently developed (Zervogianni et al., 2020), causing literature to be more limited in regard to ICT tools' design. Indeed, an important component in evaluating and helping to improve the quality of ICTs research revolves around design choices. Reviews on how to design ICT tools for people with NDD are rare. Some authors have already proposed some frameworks, but they are often proposed to a specific population, a specific ICT and specific targeted skills, which prevents them from being widely used (e.g. Carlier et al., 2020 focus on the creation of a serious game to reduce anxiety in children with ADHD; Khowaja & Salim, 2020 focus on a serious game aiming to improve vocabulary in children with ASD). Moreover, one question remains: "what are the active components of digital health intervention?" (Hollis, 2017) where active components are defined as components that have the predicted impact on the targeted outcome. Currently, no study is able to answer that question. In particular, there is no scale that can assess and score the quality of an ICT tool in terms of its design.

The Delphi technique is "a structured process that uses a series of questionnaires or 'rounds' to gather information" (Jorm, 2015). This method is appropriate when there is a lack of evidence or incomplete knowledge (Powell, 2003). It allows obtaining an expert consensus and that can be used to determine which methodologies are appropriate in medical science (Jorm, 2015). Usually, consensus is defined by a percent of agreement with a threshold of 75%, however this definition varies from one study to another (Diamond et al., 2014). In a review including 80 Delphi studies, median scores above a predefined threshold and a high level of agreement (i.e., percent of overall rating are in the highest tertile) are the most frequent method used to achieve consensus (Boulkedid et al., 2011). Even if no agreement exists regarding best criteria for obtaining consensus, a measure of distribution and a central tendency should be included. Medians appear to be more robust than means and IQR are more robust than standard deviation (Trevelyan & Robinson, 2015). The criteria of consensus should be given a priori with a limited number of rounds that should be stated prior to the Delphi study (Diamond et al., 2014; Trevelyan & Robinson, 2015). Participants received results after each round. Visual feedbacks as bar charts help with interpretation (Trevelyan & Robinson, 2015).

The Delphi method has the advantage of not requiring face-to-face contact, which facilitates wider group participation, and it allows recruiting experts, despite of their geographical location (Trevelyan & Robinson, 2015). A clear explanation should be given as to why they are considered experts. In the mental health area, experts are generally professionals (Jorm, 2015). The panel of experts should be around 20 or more participants to assure a good stability of the results. However, Delphi studies in mental health have generally much smaller panels (Jorm, 2015). Recruited experts from different backgrounds allow to produce better quality solution than homogenous groups; but, concerning clinical interventions, specialists of the specific area seem to be more appropriate (Powell, 2003). The recruitment of experts should be done based on the definition of expertise and not only on the acquittance with the researcher (Powell, 2003).

The questionnaire is generally administrated by a web survey which allows to recruit experts everywhere in the world without needing to meet virtually or in person (Jorm, 2015). Lickert scale from 1 to 9 is the more common method used in Delphi studies (Boulkedid et al., 2011). The Delphi method has already been used with those with NDD (i.e. Ali et al., 2018) and for new technologies in healthcare (i.e. Polisena et al., 2018). Zervogianni et al. (2020) have already used a Delphi method to develop a consensus on what is good evidence for ICT for people with ASD, but their work did not focus on the design of ICT.

This study is based on the Delphi method and aims to fill the gap in assessing designs concerning ICTs by creating an inventory to rate it. We first constructed a *trans*-ICT inventory based on the literature named the Design ICT Inventory (DICTI). We refer to the *trans*-ICT inventory as a tool easily adaptable from one tech to another (e.g. from serious game to robotics) by keeping a common structure and specific examples to rate the inventory according to each specific tech or modality. We first described how we identified targeted components of digital intervention and linked them to each item of the inventory thanks to a review of literature. Then, we explained how we conducted the Delphi study by collecting experts' opinions from different backgrounds and ran three rounds of modification and experts' rating in order to obtain a consensus on the inventory. We finally discussed the interest of our work and its limitations regarding the need of validation and replication of these findings.

## 2. Materials and methods

### 2.1. Selection of the items for the trans-technology inventory based on a literature review

We first constructed the *trans*-technology inventory thanks to a literature review on ICTs and NDD. Between October 29th, 2020 and November 2nd, 2020, we explored the PubMed Database with the following key-words and combinations ("design" OR "methodology" OR "framework" OR "protocol") AND ("neurodevelopmental disorder" OR "developmental disorder" OR "developmental disabilities" OR "autism" OR "developmental disorders") AND ("new technologies" OR "digital health" OR "eHealth" OR "technology based intervention" OR "technology" OR "technologies" OR "Information and communication technology" OR "ICT" OR "robot" OR "innovative technology").

We used the following criteria to select the studies: (i) they discussed how to design a tool when creating one; (ii) they reported on ICTs; (iii) they targeted individuals with NDD; and (iv) the papers were written in English. We included journals' articles, book chapters, and conferences proceedings. We excluded papers that do not have a focus on design implications; papers describing the design of their tools without discussing it and its implication for the adaptation of technologies to people with NDD; and papers about cerebral palsy. In addition, we excluded papers focusing exclusively on sensor technologies (as eyes or movement trackers, sleep assessment devices) as well as papers focusing on prosthesis or orthosis. Finally, we excluded all papers describing tools that are not in direct interaction with people with NDD: (i) tele-practice tools not designed for this population; (ii) tools for data collection as fMRI, EEG …; (iii) devices dedicated to parents or clinician (as guidance or screening).

The diagram flow is shown in Fig. 1. We found 131 articles and after screening abstracts we kept 28 articles to construct the scale. In addition to the references listed, we identified 1 additional study that met out inclusion criteria. All articles are summarized in Table 1.

Then, from the 28 articles, we listed all design components or features that the authors defined as crucial for designing a tool for individuals with NDD (see Table 2). Finally, we kept all features cited in at least 3 papers, giving us 12 features for the inventory as follows: customization, feedback, rewards, contextualized learning, enhance motivation, manage difficulty, increasing accessibility, clarity of instruction and content, attention capacity, clear goals, minimalistic graphics, and audio and human interaction. Our team decided to add one last point about trustworthy, which can be defined as the level of trust people have in ICTs to achieve the goal they are made for (Langer et al., 2019). This is a very important feature in robotics but not really considered in the other ICTs.

### 2.2. Construction of the trans-technology inventory

Based on these 13 essential features (12 from the literature selection plus trustworthiness), we constructed an inventory easy to use and adaptable to assess the presence or absence of each item within the different ICTs. The inventory appears as a matrix with two dimensions:

As we aimed to obtain a *trans*-ICT inventory, the first dimension is composed of the most common ICT's we found in the NDD literature (i.e.

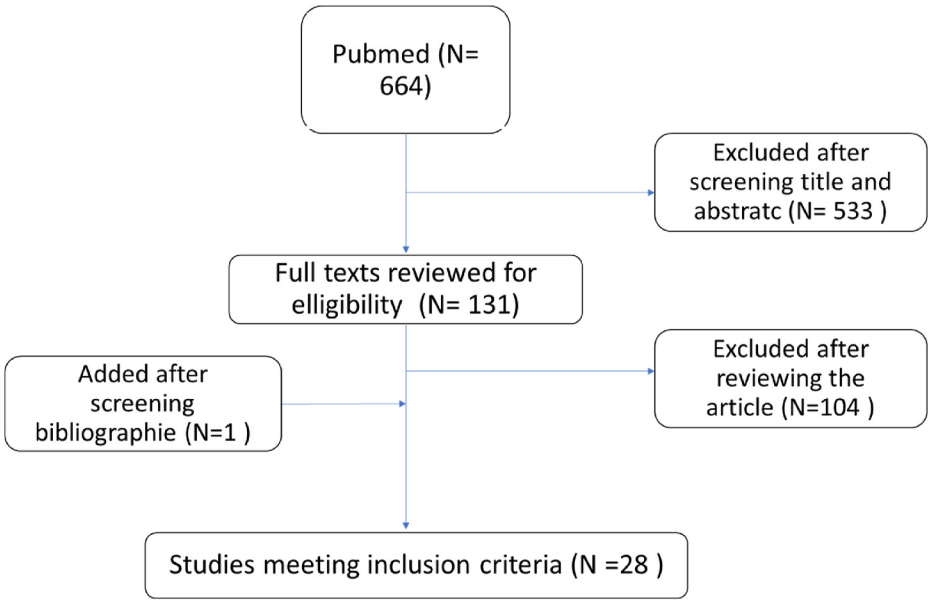


**Fig. 1.** Flow-chart of the study search.

**Table 1**
Characteristics of the studies used to construct the *trans*-technology inventory.

| Authors, year | Study design | Targeted population | Type of support | Targeted skills |
|---|---|---|---|---|
| Allen et al. (2016) | Systematic review and case study | ASD | Tablets | Communication Learning skills |
| Carlier et al. (2020) | Case study | ASD | Tablets | Anxiety |
| Dalton (2016) | Interviews | | Robots | Social skills |
| Dawe et al., 2019 | Systematic review | | Robots | All skills |
| Ganz et al. (2017) | Meta analysis | ASD and ID | Tablets | Communication Social skills |
| Grossard et al. (2017) | Systematic review | ASD | Serious games | Social skills |
| Grynszpan et al. (2014) | Meta-analysis | ASD | Serious games | Social skills |
| Guard et al. (2019) | Case study | Developmental disabilities | Tablets | Pain evaluation |
| Gyori et al. (2015) | Group of studies | ASD | Smartphones | Social skills Daily living skills |
| Hollis et al. (2017) | Meta-review | ADHD ASD | All digital interventions | All skills |
| Khan et al. (2019) | Meta-analysis | all NDD | Web based interventions (tablet and computers) | All skills |
| Liang and Wilkinson (2018) | Group of studies | ASD Down syndrome | Computers with eye tracking | Communication |
| Light and McNaughton (2012) | Review | Complex communication needs | Apps | Communication Language |
| Miguel Cruz et al. (2017) | Systematic review | ASD | Robots | All skills |
| Moon et al., 2020 | Meta-analysis | ASD | Smartphones | All skills |
| Morin et al. (2018) | Systematic review | ASD ID | Tablets and smartphones | Communication |
| Odom et al. (2015) | Systematic review | ASD | All supports | All skills |
| Park et al. (2019) | Systematic review | ASD | Virtual reality | All skills |
| Parsons et al. (2019) | Case study | ASD | Tablets | Visual motor<br>Language<br>Social skills |
| Pennisi et al. (2016) | Systematic review | ASD | Robots | Social skills |
| Powell et al. (2019) | Interviews | ADHD | Serious games | Self management of ADHD |
| Quezada et al. (2017) | Group studies | ASD | Tablets | Motor skills |
| Root et al. (2017) | Systematic review | ASD | Computers | Academic skills |
| Sandbank et al., 2020 | Meta analysis | ASD | All supports | All skills |
| Scassellati et al. (2012) | Review | ASD | Robots | Social skills |
| Tang et al. (2019) | Interview | ASD | Serious games | Emotion recognition |
| Whyte & Scherf (2015) | Systematic review | ASD | Computers | All skills |
| Zervogianni et al. (2020) | Interview | ASD | All supports | All skills |

ASD: autism spectrum disorder; ID: intellectual disability.

Grossard et al., 2017, Powell et al., 2019; Whyte & Scherf, 2015). We classified them in 4 subcategories: (i) Serious games and Apps (SGA) which are games with an educative purpose (Whyte et al., 2015), (ii) Robots and more precisely assistive robotics and social robotics (Scassellati et al., 2012), (iii) Augmentative and Alternative Communication (AAC) which, among others, refers to a wide variety of technologies which supports communication in individuals with complex communication needs (Wilkinson & Madel, 2019) and (iv) Video Modeling (VM) who are technologies aiming to support independent performance of individuals with special needs (Odom et al., 2015).

The second dimension is composed with the 13 items to rate. Each item can be rated using a Likert-scale between 0 (absence) and 2 (fully considered). To help raters score, each item was connected to targeted skills that ICTs design aims to support. We identified 10 targeted skills:

**Table 2**
List of features found in the 28 studies from the literature review.

| Essential features | | |
|---|---|---|
| Features | Examples | Studies |
| Customization: learner's control and choice | Customize the characters and the environment<br>Customize pictures<br>Control some function in the game like duration or order of the exercises<br>Nonlinear gameplay<br>Different pathways in function of the profile<br>Personalized messages<br>Personalized content as possibility to photograph objects in AAC | Carlier 2020; Whyte 2015; Grossard (2017); Dalton, 2016; Tang (2019); Parsons (2019); Powell (2019); Zervogianni (2020); Hollis (2017); Allen (2016); Strickland 2007; |
| Feedback must be clear that the goal has been reach | Specific sound when the answer is correct<br>No negative feedback<br>Progression bar | Carlier 2020; Whyte (2015); Grossard (2017); Tang 2019; Powell (2019); Strickland 2007; |
| Rewards | There should not be penalty points<br>Obtain new objects<br>System of points to obtain objects or customize the game<br>Providing encouragement | Carlier 2020; Whyte (2015); Grossard (2017); Tang 2019; Powell (2019) |
| Gamification with storyline: to enhance motivation and contextualized learning | Including a companion or an enemy in the game<br>Real life scenario<br>Joke or humor<br>The storyline must not be too complex to avoid the child losing the main goal of the game<br>Downloadable gaming resources | Whyte (2015); Tang (2019); Carlier (2020); Grossard (2017); Parsons (2019); Powell (2019) |
| Evolving task: increasing gradually the level of difficulty for each exercise and from an exercise to another in function of the player | Construct the game to automatically adapt to the level of the player<br>Allow the user to adapt manually the difficulty.<br>This adaptation must be easy and quick: if the change of level is difficult or time consuming between games, there's a risk of losing the player.<br>The game must be challenging but accessible<br>Scaffolding: providing assistance to help the player when a task is hard or new. Then decrease the scaffolding<br>Implementing « auto correct » and « multi-choice options » to support player during difficult games | Carlier 2020; Whyte (2015); Grossard (2017); Tang 2019; Powell (2019); Zervogianni (2020); Allen (2016) |
| Simplicity to use to promote accessibility | Minimize the number of gestures require<br>Simple gesture needed<br>Familiar hardware i.e.<br>Repetitive placement of buttons<br>Easy to use even for non-technologically advanced people<br>Be compatible with accessibility features available like zoom or voiceover on iPad<br>Taking into account required motor skills and action (drag, swipe …)<br>Taking into account visual-perceptual characteristics of the display regarding visual skills of the population<br>Taking into account cognitive skills as non-verbal comprehension, memory …<br>Simplicity to use for parents or caregivers: avoid time consuming apps | Dalton, 2016; Parsons 2019; Khan 2019; Zervogianni 2020; Guard 2019; Quezada 2017; Strickland 2007; Liang et al., 2018; Light et al., 2012 |
| Clarity of the instructions and content | Short instructions<br>Tutorial<br>Language suitable to developmental age<br>Visual symbols easily comprehensive (Light 2012 AAC)<br>No figure of speech<br>Reminders during tasks<br>Using video instead of pictures could help representing actions | Carlier 2020; Grossard (2017); Powell (2019); Strickland 2007; Light et al., 2012 |
| Attention capacity | Diminish transition time between games (i.e. loading)<br>Using dynamic stimuli to keep the player awake<br>Avoiding unnecessary distractors | Carlier 2020; Grossard (2017); Strickland (2007) |
| Clear goals at short and long term | One unique goal per gaming session (Carlier, 2020)<br>Differentiate immediate goal (like goal of a game) and long term goal (like goal of the story) | Carlier 2020; Whyte (2015); Tang 2019; Powell 2019 |
| Minimalistic graphics and audio: keep the environment pleasant but avoid non-essential cues | Avoid non-essential animations to avoid repetitive behaviors<br>Giving the possibility to turn off music or sound effects separately<br>Giving possibility to customize graphics as character font or background color | Carlier 2020; Dalton, 2016; Powell (2019) |
| Human interaction during the game | Cooperative multiplayer games increase prosocial behaviors<br>Integrating other player may favorize engagement<br>Possibility to receive encouragement from families or friends | Carlier 2020; Whyte, 2015; Powell 2019 |
| **Non-essential features** | | |
| Predictability: effects must be predictable even if the content can be serendipitous | A random object appears at the end of each task | Carlier, 2020 |
| Repeatability | Practice | Carlier, 2020; Grossard, 2017 |

motivation, identify the targeted task, learning, generalization, social context, attention, fatigability, repetitive behaviors, social interaction, and accessibility. Then, we offered indications for rating items and provided examples for each of the four subcategories of ICTs.

### 2.3. Delphi study validation

By using the first version of the DICTI that was theoretically constructed based on the literature review and inputs from our team, we conducted a Delphi study to improve the inventory with inputs from three independent external experts from each ICT's subcategory. We contacted 25 experts and found 12 who would help us with our research. Each expert was identified thanks to our network and the literature review. An individual was deemed an expert if she or he (i) had published at least 2 articles in peer review journals about one of the 4 domains of ICTs that we identified, (ii) had implemented specific ICTs in regards to educational and therapy purposes and published at least 1 one experimental study in a peer reviewed journal. We coupled each expert to an ICTs' subcategory depending on the field in which they have published about (SGA, robots, CAA or VM).

To perform the Delphi study, we created a specific online survey to collect survey responses and followed a three-round approach for the study (Jorm, 2015; Trevelyan & Robinson, 2015). The DICTI was sent to the experts with an online questionnaire that each expert had to fill out anonymously. No meetings with the experts were necessary. For the first round, experts had to rate each item twice on a Likert scale from 1 (totally disagree) to 9 (totally agree). The first rating concerned the item in its globality (all ICTs together), and the second rating concerned only the ICT they were expert in (the subcategory of ICT for which the expert was identified). For each item of the inventory, the experts could add additional comments. Participants responded within 2–8 weeks. All of the experts received a feedback on the results of the first round. As recommended by Trevelyan and Robinson (2015), we provided the score for each item given by the expert, a measure of central tendency (median of the score), and a measure of the distribution (inter-quartile range). We also included a visual feedback with a bar-chart to help the interpretation and the comments of the experts, if any.

Following this first round, conducted between the February 8, 2021 and the March 21, 2021, we worked on all the items to integrate all the comments of the experts' panel. For the second round, conducted between the 29th March and the April 30, 2021, we asked the experts to assess each item again as all of the items were modified following the first round. As for the first round, each expert had to rate each item twice on the same Likert scale previously mentioned. We defined consensus for a given item as the extent to which participants agreed with each other and agreement as the extent which participants agreed with each item. To validate an item, we wanted to reach agreement and consensus for this item. As both of them were reach after the second round, we didn't need a third round.

For the global rating (rating about all ICTs), we evaluated the consensus thanks to the interquartile range (IQR), which is an objective and rigorous way of determining consensus (Von der Gracht, 2012). Consensus is considered as reached if IQR $<1.5$. The agreement was evaluated thanks to the median that has to be superior to 7 and the percentage of agreement (% of score within the 7 to 9 area) that has to be superior to 90%. Each item that reached agreement and consensus was considered as appropriate. For the rating of the item by ICTs' subdomains (3 experts by ICT), we only used the median to evaluate the agreement with the item in order to be sure that each item of the inventory was adapted to each ICT. We obtained 100% response rate for each item for each round of the Delphi study.

## 3. Results

Twelve experts composed the panel (8 women and 5 men). They are from all over the world (USA = 4, France = 3, Australia = 1, Cyprus = 1, Switzerland = 1, Turkey = 1, United Kingdom = 1). They were equally distributed among the four subcategories of ICTS (three experts per domain). Their background included child psychiatry, special education, psychology, engineering, robotics, and computational science. Results from the first and second round for the global rating are presented in Table 3. Percentage of agreement represents the percentage of score within the 7 to 9 area of the Likert scale from 1 to 9.

No item was removed or added between round 1 and 2 as (i) a majority of the experts estimated that all items of the inventory were relevant (median for the global rating $\geq 7$ for all items) and (ii) no experts suggested adding an item. However, agreement was not reach for all specific rating by ICT (see Table 4). Finally, every item was modified after the first round to include all the comments of the experts.

After round 1, we identified different types of modifications to be made. (i) Modifying titles of the items: items 6, 10 and 11 have been changed to better fit with all types of ICT (i.e., item 10 "Clear goals for short and long term" became "Clear **steps or** goals for short and long term" to better fit with AAC and VM). (ii) Adding examples: we completed each list of examples with new ones that were suggested by the experts. These features could be specific to an ICT (i.e., item 4, we added in VM "choice between first or third person view") or could be added for all ICTs (i.e. item 13, we added for all ICTs "Impact on the user and its environment should be consider (i.e. how to adapt the device to daily life)"). (iii) Adding precisions: some statements needed to be better defined to assure a good comprehension. It was mostly resolved by adding precisions for each unclear point (i.e. for robot and SG, the example "Provides encouragement" for the item 5 became "Provides encouragement (i.e. saying "good job!"). (iv) Adapting terminology: we modified some terms to better fit with the terminology of each ICT (i.e. using "symbols" instead of "pictures" for items related to AAC). All modifications between round 1 and 2 can be found in supplementary material.

Concerning global rating, a good level of consensus (IQR $<1.5$) and agreement (median $>7$) were reached for all the items after round 2. For each ICTs rating, agreement was also reached after round 2. The final version of the inventory can be found in Table 5.

## 4. Discussion

We conducted a Delphi study in order to reach a consensus about the features that well-designed ICTs tools for people with NDD should provide. The interest of this work is to consider that these features can be related to targeted skills that are considered by the most common ICT subcategories (AAC, robots, VM and SG/App). Based on that, we were able to develop a *trans*-ICT inventory, the DICTI, that can be used to improve the design of ICTs and compare tools in terms of design efforts. In order to facilitate the use of the inventory, we proposed different examples of characteristics that can be related to a specific feature and a specific ICT.

The Delphi technique allowed collecting experts' opinions in the four ICTs subcategories we identified. We asked the experts to assess the inventory twice: one global rating for all ICTs and one rating specific to the ICT falling in their field of expertise (Jorm, 2015; Trevelyan & Robinson, 2015). The global rating allowed us to be sure that each of the items of the inventory were relevant and adapted to a targeted skill we identified. After the second round, all items reached the threshold for IQRs and medians, and we defined to verify consensus and agreement. The specific rating was necessary to ensure that each item was adapted regarding to the targeted ICT. For each ICTs, the median of 7 was reached for all the items of the DICTI (Von der Gracht, 2012).

The creation of the DICTI pursues two main objectives. The first is to provide an efficient tool to guide the design of ICTs and/or gauge the ICT's adequacy to best practices found in the literature. This inventory is relatively short with only 13 items, and no experts suggested adding more features. We believe that the DICTI should be easy to use and relatively quick to rate. The particularity of this inventory is the providing of examples related to each ICT that illustrate each feature and so facilitates the comprehension of what they represent. The objective is to allow anyone to use this inventory without specific training. However, it can only be used after a rater practices using the ICT tool they want to rate. Researchers, NDD's professionals,

**Table 3**
Results of experts' global rating for Delphi rounds 1 and 2.

| Round 1: global rating | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Items | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Median | 7 | 8 | 8.5 | 7 | 7.5 | 8 | 7.5 | 9 | 8.5 | 8 | 9 | 8 | 9 |
| IQR | 2.5 | 2.5 | 2 | 2 | 2.25 | 3.25 | 2.25 | 1 | 2 | 2.25 | 1.25 | 2.25 | 1 |
| % agreement | 75 | 75 | 91.6 | 83.3 | 75 | 58.3 | 75 | 83.3 | 83.3 | 75 | 83.3 | 83.3 | 100 |
| Round 2: global rating | | | | | | | | | | | | | |
| Items | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Median | 9 | 9 | 8 | 8 | 8 | 9 | 9 | 9 | 8.5 | 8.5 | 9 | 9 | 9 |
| IQR | 1.25 | 1.25 | 1.25 | 1 | 1 | 1 | 1 | 1 | 1 | 1.25 | 1 | 1 | 1 |
| % agreement | 91.6 | 91.6 | 91.6 | 91.6 | 100 | 100 | 100 | 100 | 100 | 91.6 | 100 | 100 | 91.6 |

Item 1: Possible customization by the user; 2: Feedback; 3: rewards; 4:contextualized learning; 5: Enhance motivation; 6: Manage difficulty or complexity; 7: Increasing accessibility:simplicity to use and autonomy; 8: clarity of the instructions or content; 9: Attention capacity; 10: Clear steps or goals for short and long term; 11: Easy to process and modify graphics and audio: keep the environment pleasant but avoid non-essential elements; 12: Human Interaction; 13: Trustworthy.

**Table 4**
Median of experts' specific rating by ICT for Delphi rounds 1 and 2.

| Round 1: specific rating | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Items | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Robots | 8 | 3 | 4 | 7 | 7 | 6 | 6 | 8 | 6 | 5 | 6 | 6 | 7 |
| Serious games & Apps | 9 | 8 | 9 | 8 | 6 | 9 | 9 | 9 | 9 | 8 | 9 | 9 | 9 |
| AAC | 9 | 9 | 9 | 9 | 6 | 4 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| VM | 9 | 6 | 7 | 9 | 8 | 7 | 8 | 9 | 7 | 7 | 9 | 7 | 9 |
| Round 2: specific rating | | | | | | | | | | | | | |
| Items | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Robots | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 9 | 8 | 7 | 7 | 8 | 7 |
| Serious games & Apps | 9 | 9 | 9 | 8 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| AAC | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| VM | 9 | 9 | 9 | 8 | 9 | 9 | 9 | 8 | 8 | 8 | 9 | 9 | 9 |

Item 1: Possible customization by the user; 2: Feedback; 3: rewards; 4: contextualized learning; 5: Enhance motivation; 6: Manage difficulty or complexity; 7: Increasing accessibility:simplicity to use and autonomy; 8: clarity of the instructions or content; 9: Attention capacity; 10: Clear steps or goals for short and long term; 11: Easy to process and modify graphics and audio: keep the environment pleasant but avoid non-essential elements; 12: Human Interaction; 13: Trustworthy.

developers, engineers and users can use the inventory in order to develop tools adapted to people with NDD based on an international consensus and so that should be use in any country. Currently, most of the research in this area does not provide a simple tool that can be easily used to this purpose, whereas people with NDD, their families and professionals are asking for a tool to quickly evaluate if an ICT is adapted to people with NDD (Zervogianni et al., 2020). Some specific tools have been developed for one specific NDD or on specific skills, like reading or social skills, but they cannot be widely used (E.g., Khowaja & Salim, 2020 for vocabulary in children with ASD). Given the high rates of comorbidities between NDD, the use of this inventory should encourage researchers to develop tools adapted to all NDD (Xavier et al., 2020). In addition, most of the design inventories developed targeted one particular type of ICT's such as serious game or robots (e.g., Scassellati et al., 2012 for robots; Whyte et al., 2015 for serious games). This work supports the idea that a design framework can be constructed based on design aspects that are crucial components to consider when working with people with NDD.

The second objective of this inventory is to raise a consensus about which features composed a well-designed ICT for NDD. With a clear consensus, it becomes possible to define the main components an ICT should include. This should help the community in two ways if the inventory is well accepted. First, it should decrease the variability between studies. Currently, the design can widely vary from one tool to another, and it makes the comparison between them hard to make (Grossard et al., 2017). This leads to the second point for which DICTI can be useful, that is the assessment of technologies. The method to assess technologies differs from one paper to another; mostly because the objectives of the studies are defined by the skills they want to work on (i.e. attention, social skills, academic skills …) more than the specific features that should have an ICT (Hollis et al., 2017). Building a tool dedicated to the specific features of ICTs should help clarifying and reducing the heterogeneity in the field. With a better tool to understand the features of ICTs, it offers the possibility to better assess the effect of each of these features. We believe that this type of work will likely improve how we can deal with the question asked by Hollis (2017) and understand what the active components in ICTs are.

### 4.1. Limitations and future studies

A Delphi study only offers a consensus statement when no or little literature is available (Powell, 2003). In our case, it helps creating and then improving a Design ICT Inventory applicable to all subcategories of ICT that can be used with people with NDD. We contacted experts from different countries who worked on developing ICTs for people with NDD. None of the experts were design engineers despite of having worked with teams who developed or adapted ICT's to this population. We also did not involve peopled with NDD in the panel of experts.

We recruited 12 experts, which correspond to a usual sample size in health-related Delphi study (Trevelyan & Robinson, 2015). However, panels of less than 20 experts may produce unstable findings (Jorm, 2015). In order to compensate this small panel of experts, for the global rating, we used elevated thresholds to ensure that each item was relevant and were able to obtain consensus and agreement for each of them (Von der Gracht, 2012). We made a specific rating by ICT to verify that each item was adapted regarding each ICT. However, we only had three experts for each of the ICT, which does not allow us to rate consensus for each ICT. Moreover, the inventory needs to be validated with proper validation study to calculate interrater agreements in several NDDs and different ICT subcategories. This should be done in future research.

If the DICTI seems relevant to assess the design of an ICT, it is not sufficient in itself to assess the global quality of it. Our inventory is a complementary tool that should be used with other scales and methods that are relevant to create and assess an ICT. Indeed, participatory

**Table 5**
Final version of the Design ICT Inventory (DICTI).

| Features and Targeted Skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| 1. Possible customization by the user | 0: No personalization | - Customize the characters and the environment | - Appearance of the robots (size, color, form etc.) | - Customized audio and video | - Customized audio and video |
| | 1: Partially considered | - Ability to modify length or order of the exercises | - Characteristics of the robot (gesture, way to control it …) | - Customized messages | - Customized messages |
| TS: motivation | 2: Fully considered | - Different pathways in regard to the user's profile | - Control duration or order of the exercises | - Possibility to arrange the position of the navigation bar | - Ability to select model/actor in video |
| | | - Personalized messages | - Different pathways in regard to the user's profile | - Possibility to select a preferred set of graphic symbols and/or create individualized symbols (i.e. by taking a photo) | |
| | | | - Personalized messages | | |
| 2. Feedback | 0: No feedback | - Specific feedback (i.e. sound or visual bar) when the answer is correct | - Specific feedback (i.e. sound, gestures, body postures, colors) when the answer is correct | - Auditory feedback when choosing symbols | - Opportunity for the user to auto-correct (i.e. including a step to check what was already done) |
| | 1: Feedback but is not clearly related to a goal | - Progression bar/timer | - Each feedback is related to a targeted skill | - Sentence construction: automatic adaptation of grammar and syntax | |
| TS: identify the targeted task | 2: Feedback clearly related to a goal | - Provide visual feedback on progress within the app (i.e. learning map) | - Possibility to provide only positive feedback | | |
| | | - Possibility to provide only positive feedback | | | |
| 3. Rewards | 0: No rewards | - Social reinforcement (i.e. applause) | - Social reinforcement (i.e. applause, dance, emotional expressivity) | - Social reinforcement (i.e. at the end of a task in VM) | - Social reinforcement (i.e. at the end of a task in VM) |
| | 1: Social reinforcement (applause) or points only. | - Visual or auditory rewards (video, pictures, songs …) | - Visual or auditory rewards (video, pictures, songs …) | - Visual or auditory rewards (video, pictures, songs …) | - visual or auditory rewards (video, pictures, songs …) |
| *TS: motivation and learning* | 2: Rewards like objects, videos, song | - Points | | | |

| Features and Targeted skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| 4.Contextualized learning | 0: None | - Introduction of real-life scenario | - Scenario must be designed to allow children to draw connections between themselves and their everyday life | - AAC can include video modeling | - Opportunity to create sequences featuring the user as the model (video-self modeling) |
| | 1: Scenario not clearly linked with user's environment | - Downloadable gaming resources | - scenario are associated with everyday life activities to encourage interaction | - technology offers option to select grid-type display or VSD | - Ability to create videos featuring user's actual environment. |
| TS: generalization and social context | 2: Clear link between scenario and user's environment | - choice between first- or third-person view | | - Add hotspot to VSD by drawing on the screen | - choice between first- or third-person view |
| | | | | - available pre-stored vocabulary to illustrate common context | |
| 5. Enhance motivation | 0: None | - Includes a companion or enemy in the game | - Robot must be friendly (i.e.: adapted size and appearance) to engage with the children | - Ability to communicate individualized and preferred topics | - Provides encouragement |
| | 1: Partially considered | - Contains jokes or humor | - Provides encouragement (i.e. saying "good job!") | - Integrated a variety of functions of communication (i.e., telephone, play situation …) | - Motivating factors such as humor or encouragement can be added to videos |
| TS: motivation | 2: Fully considered | - Provides encouragement (i.e. saying "good job!") | - being non-judgmental | | |
| 6. Manage difficulty or complexity | 0: No difference between levels | - The game automatically adapts to the player's performance | - Adapt scaffolding according to scenario and user capacities (i.e. robot can first initiate the interaction, then just support it) | - Choose between different types of symbols (pictures, photographs, traditional orthography/written words) to fit with the level of comprehension of the user | Possibility to see each sequence (video prompting) or all tasks at once (video modeling) |
| | 1: Changes in difficulty without adapting to the player | - Allow the user to adapt manually the difficulty | - Possibility to manage the linguistic difficulty to fit with the user's skills | - Choose between the number of symbols presented in each communication page and in the entire communication book | - Possibility to manage the linguistic difficulty to fit with the user's skills |

(*continued on next page*)

**Table 5** (*continued*)

| Features and Targeted skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| TS: accessibility and learning | 2: Changes in difficulty in regard to the player (manually or automatically) | - Adapt scaffolding (i.e. provides full support at the beginning of a new task and then diminished it)<br>- Evolving task with increasing difficulty<br>- Possibility to manage the linguistic difficulty to fit with the user's skills<br>- Ability to modify the speed of displaying stimuli | - Ability to modify the speed of displaying stimuli | - Possibility to manage the linguistic difficulty of the vocabulary to fit with the user's skills | - Ability to modify the speed of displaying stimuli |

| Features and Targeted skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| 7. Increasing accessibility: simplicity to use and autonomy | 0: None | - Simple to use for parents or caregivers (avoids time consuming apps) | - Simple to use for parents or caregivers (avoids time consuming by favoring autonomy of the robots) | - Simple to use for parents or caregivers (avoids time consuming apps) | - Simple to use for parents or caregivers (avoids time consuming apps) |
| | 1: Partially simple (i.e. simple gestures but time consuming) | - Minimizes the number of gestures/click required | - Minimizes the number of gestures required | - Minimizes the number of gestures/click required | - Minimizes the number of gestures/click required |
| *TS: accessibility* | 2: Easy to use and easily accessible | - Simple actions needed to interact with the support (i.e. keystroke or tapping are easier than drag or swipe)- Easy to use even for non-technologically advanced people<br>- Not related to a specific device or operating system | - Simple actions needed to interact with the robot, adapted to the user<br>- Easy to use even for non-technologically advanced people | - Simple actions needed to interact with the support (i.e. keystroke or tapping are easier than drag or swipe)<br>- Integrate word prediction to support easy access<br>- Easy to use even for non-technologically advanced people<br>- Not related to a specific device or operating system | - Simple actions needed to interact with the support (i.e. keystroke or tapping are easier than drag or swipe)- Easy to use even for non-technologically advanced people<br>- Not related to a specific device or operating system<br>- Can be watched on devices with built in accessibility features |
| 8. Clarity of the instructions and content | 0: None | - Contains a tutorial | - Language suitable to developmental age | - Language suitable to developmental age | - Language suitable to developmental age |
| | 1: Language adapted but not visual | - Language suitable to developmental age | - Reminder during task | - Visual symbols easily comprehensive | - Videos are easily understood |
| TS: accessibility | 2: Visual and language adapted | - Visual symbols easily comprehensive<br>- Reminder during tasks | - Robot's actions must be simple and easily understood by the user | - Using animated symbols instead of pictures to help representing actions | - Using videos instead of pictures to help understanding actions |
| 9. Attention capacity | 0: None | - Uses stimuli to keep the player engaged | - Adapts the length of tasks depending on the population and scenario | - Allows real time communication (i.e. with pre-registered sentences, prediction of words/ sentences) | - Adapts the length of the video |
| | 1: Adaptation of duration OR stimuli to keep the user engaged | - Adapts the length of tasks | - Uses stimuli to keep the player engaged | - Relieve working memory by keeping the current sentence visible while looking for the next image | - Uses stimuli to keep the user engaged |
| TS: Attention and fatigability | 2: Adaptation of duration AND stimuli to keep the user engaged | - Diminish transition time between games | | | |

| Features and Targeted skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| 10. Clear steps or goals for short and long term | 0: None | - Favorized one unique goal per gaming session | - Favorized one unique goal per gaming session when possible, according to the situation | - Clear and simple organization (i.e. clearly identify category inside a folder by provide a | - Each step should be easily identified by the user (i.e.: One video could be related to one step) |

(*continued on next page*)

**Table 5** (*continued*)

| Features and Targeted skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| | | | | compilation of images instead of one single related image) | |
| | 1: Limited number of steps/goals in a session OR clear goals | - Differentiation between the immediate goal (goal of a game) and long-term goal (goal of the story) | - Differentiation between the immediate goal (i.e. joint attention) and long-term goal (enhance social skills) | - Thumbnails are clearer than symbols | - Differentiation between the immediate step (i.e. open the fridge) and long-term goal (i.e. make a sandwich) |
| *TS: accessibility and learning* | 2: Limited number of steps/goals AND clear steps/goals | | | - Limiting the number steps (i.e. number of location levels) | |
| 11. | 0: None | - Avoids non-essential animations to prevent repetitive behaviors | - Avoids non-essential animations to prevent repetitive behaviors | - Has controls for the sounds | - Has controls for the sounds |
| Easy to process and modify graphics and audio: keep the environment pleasant but avoid non-essential elements | 1: Minimalistic graphics OR sounds | - Gives the possibility to customize graphics as character's font or background color | - Has controls for the sounds | - Gives the possibility to customize graphics as character's font or background color | - Control over the video (location, actors, props) |
| | 2: Minimalistic graphics AND sounds | - Gives the possibility to turn off music or sound effects separately | - Animations, sounds and color should be appropriate to the targeted user (in terms of age, skills …) | - Animations, sounds and color should be appropriate to the targeted user (in terms of age, skills …) | - Gives the possibility to customize video elements such as graphics, font or background color |
| TS: repetitive behavior and attention | | - Animations, sounds and color should be appropriate to the targeted user (in terms of age, skills …) | | | - Animations, sounds and color should be appropriate to the targeted user (in terms of age, skills …) |

| Features and Targeted skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| 12. Human interaction | 0: None | - Cooperative multiplayer games with caregivers | - Cooperative multiplayer games with caregivers | - Ability to exchange messages with caregivers or family through social media channel and text messaging | - Ability for caregiver or family to create videos |
| | 1: Exchange with one person | - Cooperative multiplayer games with peers | - Cooperative multiplayer games with peers | - Ability to exchange messages with peers through social media channel and text messaging | - Ability for user to exchange videos with peers |
| *TS: social interaction and motivation* | 2: Multi-users exchange | - Possibility to receive encouragement from family, caregiver, or friends | - support interaction between the user and others according to the user capacity | | |
| 13. Trustworthy | 0: None | - Assures safety and cybersecurity if needed | - Assures safety and cybersecurity if needed | - Assures safety and cybersecurity if needed | - Assures safety and cybersecurity if needed |
| | 1: Partially considered | - Is robust: avoids bugs and latencies | - Is robust: avoids bugs and latencies | - Is robust: avoids bugs and latencies | - Is robust: avoids bugs and latencies |
| TS: motivation and accessibility | 2: Fully considered | - Clear goals and operation of the device | - Clear goals and operation of the device | - Clear goals and operation of the device | - Clear goals and operation of the device |
| | | - Impact on the user and its environment should be consider (i.e. avoid obsession with the ICT, how to adapt the device to daily life) | - Behavior of the robots must be predictable and understandable to enhance trust | - Impact on the user and its environment should be consider (i.e. how to adapt the device to daily life) | - Impact on the user and its environment should be consider (i.e. how to adapt the device to daily life) |
| | | | - Impact on the user and its environment should be consider (i.e. how to adapt the device to daily life) | | |

design is an important step that is necessary to ensure the ICT is adapted to the targeted population (Frauenberger, 2015). This can be made by consulting users and professionals during the design phase of an ICT through focus group (Tang et al., 2019). Involving both professionals and users is necessary as these groups may differ with regard to the relative importance they placed on varying components of an ICT tool (Parsons & Cobb, 2014). Usability studies are also needed to assess how users interact with the device and are a crucial step to adapt the ICT to the user and their environment (Williams et al., 2006). Finally, strong methodological studies assessing the efficiency and efficacy of ICTs in general are needed. Currently, ICTs appears promising but methodological limitations and small samples sizes do not allow to conclude about their effectiveness (Khan et al., 2019).

## 5. Conclusion

We constructed the DICTI in order to provide a simple tool to assess the design of current ICTs: robots, serious games and apps, AAC and video modeling. We then conducted a Delphi study in order to validate the items of the inventory. Finally, we obtained a *trans*-technology

inventory with 13 items that were validated by 12 international experts. We obtained a quick and easy tool to assess the design of ICTs. Future works should explore psychometric validation of DICTI study (e.g. inter rater reliability). We also think this type of work could be extended to other populations with special needs as well as to the general population.

## Authors contributions

Grossard Charline: Investigation, formal analysis, writing. Carlotta Bettancourt & Kellems Ryan: Review & editing. Cohen David & Chetouani Mohamed: Review & editing, Supervision.

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## Declaration of competing interest

None.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chbr.2022.100261.

* all the papers found in our literature review

## References

Ali, N., Rigney, G., Weiss, S. K., Brown, C. A., Constantin, E., Godbout, R., … Corkum, P. V. (2018). Optimizing an eHealth insomnia intervention for children with neurodevelopmental disorders: A Delphi study. *Sleep Health, 4*(2), 224–234. https://doi.org/10.1016/j.sleh.2017.12.008

*Allen, M. L., Hartley, C., & Cain, K. (2016). iPads and the use of "apps" by children with autism spectrum disorder: do they promote learning? *Frontiers in Psychology, 7*, 1305. https://doi.org/10.3389/fpsyg.2016.01305

American Psychiatric Association. (2015). *Neurodevelopmental disorders: DSM-5® selections*. American Psychiatric Pub.

Boucenna, S., Narzisi, A., Tilmont, E., Muratori, F., Pioggia, G., Cohen, D., & Chetouani, M. (2014). Interactive technologies for autistic children: A review. *Cognitive Computation, 6*(4), 722–740. https://doi.org/10.1007/s12559-014-9276-x

Boulkedid, R., Abdoul, H., Loustau, M., Sibony, O., & Alberti, C. (2011). Using and reporting the Delphi method for selecting healthcare quality indicators: A systematic review. *PLoS One, 6*(6), Article e20476.

*Carlier, S., Van der Paelt, S., Ongenae, F., De Backere, F., & De Turck, F. (2020). Empowering children with ASD and their parents: Design of a serious game for anxiety and stress reduction. *Sensors, 20*(4), 966. https://doi.org/10.3390/s20040966

*Dalton, C. (2016). Interaction design in the built environment: Designing for the 'universal user. *Studies in Health Technology and Informatics, 229*, 314–323. PMID: 27534322.

*Dawe, J., Sutherland, C., Barco, A., & Broadbent, E. (2019). Can social robots help children in healthcare contexts? A scoping review. *BMJ paediatrics open, 3*(1). https://doi.org/10.1136/bmjpo-2018-000371

Diamond, I. R., Grant, R. C., Feldman, B. M., Pencharz, P. B., Ling, S. C., Moore, A. M., & Wales, P. W. (2014). Defining consensus: A systematic review recommends methodologic criteria for reporting of Delphi studies. *Journal of Clinical Epidemiology, 67*(4), 401–409.

Frauenberger, C. (2015). Rethinking autism and technology. *Interactions, 22*(2), 57–59. https://doi.org/10.1145/2728604

*Ganz, J. B., Morin, K. L., Foster, M. J., Vannest, K. J., Genç Tosun, D., Gregori, E. V., & Gerow, S. L. (2017). High-technology augmentative and alternative communication for individuals with intellectual and developmental disabilities and complex communication needs: A meta-analysis. *Augmentative and Alternative Communication, 33*(4), 224–238. https://doi.org/10.1080/07434618.2017.1373855

*Grossard, C., Grynspan, O., Serret, S., Jouen, A. L., Bailly, K., & Cohen, D. (2017). Serious games to teach social interactions and emotions to individuals with autism spectrum disorders (ASD). *Computers & Education, 113*, 195–211. https://doi.org/10.1016/j.compedu.2017.05.002

*Grynszpan, O., Weiss, P. L., Perez-Diaz, F., & Gal, E. (2014). Innovative technology-based interventions for autism spectrum disorders: A meta-analysis. *Autism, 18*(4), 346–361. https://doi.org/10.1177/1362361313476767

Guard, A., Konz, M., Smith, R. O., Engel, J. M., & Keating, T. (2019). The development of an iPad application for the pain assessment of individuals with developmental disabilities and complex communication needs. *Assistive Technology*, 1–12. https://doi.org/10.1080/10400435.2019.1612797

Gyori, M., Stefanik, K., & Kanizsai-Nagy, I. (2015). Evidence-based development and evaluation of mobile cognitive support apps for people on the autism spectrum: Methodological conclusions from two R+ D projects. August. In *AAATE Conf.* (pp. 55–62).

*Hollis, C., Falconer, C. J., Martin, J. L., Whittington, C., Stockton, S., Glazebrook, C., & Davies, E. B. (2017). Annual Research Review: Digital health interventions for children and young people with mental health problems–a systematic and meta-review. *Journal of Child Psychology and Psychiatry, 58*(4), 474–503. https://doi.org/10.1111/jcpp.12663

Jorm, A. F. (2015). Using the Delphi expert consensus method in mental health research. *Australian and New Zealand Journal of Psychiatry, 49*(10), 887–897. https://doi.org/10.1177/0004867415600891

*Khan, K., Hall, C. L., Davies, E. B., Hollis, C., & Glazebrook, C. (2019). The effectiveness of web-based interventions delivered to children and young people with neurodevelopmental disorders: Systematic review and meta-analysis. *Journal of Medical Internet Research, 21*(11), Article e13478. https://doi.org/10.2196/13478

Khowaja, K., & Salim, S. S. (2020). A framework to design vocabulary-based serious games for children with autism spectrum disorder (ASD). *Universal Access in the Information Society, 19*(4), 739–781. https://doi.org/10.1007/s10209-019-00689-4

Langer, A., Feingold-Polak, R., Mueller, O., Kellmeyer, P., & Levy-Tzedek, S. (2019). Trust in socially assistive robots: Considerations for use in rehabilitation. *Neuroscience & Biobehavioral Reviews, 104*, 231–239. https://doi.org/10.1016/j.neubiorev.2019.07.014

*Liang, J., & Wilkinson, K. (2018). Gaze toward naturalistic social scenes by individuals with intellectual and developmental disabilities: Implications for augmentative and alternative communication designs. *Journal of Speech, Language, and Hearing Research, 61*(5), 1157–1170. https://doi.org/10.1044/2018_JSLHR-L-17-0331

*Light, J., & McNaughton, D. (2012). Supporting the communication, language, and literacy development of children with complex communication needs: State of the science and future research priorities. *Assistive Technology, 24*(1), 34–44. https://doi.org/10.1080/10400435.2011.648717

*Miguel Cruz, A., Rios Rincon, A. M., Rodriguez Duenas, W. R., Quiroga Torres, D. A., & Bohórquez-Heredia, A. F. (2017). What does the literature say about using robots on children with disabilities? *Disability and Rehabilitation: Assistive Technology, 12*(5), 429–440. https://doi.org/10.1080/17483107.2017.1318308

*Moon, S. J., Hwang, J., Hill, H. S., Kervin, R., Birtwell, K. B., Torous, J., … Kim, J. W. (2020). Mobile device applications and treatment of autism spectrum disorder: A systematic review and meta-analysis of effectiveness. *Archives of Disease in Childhood, 105*(5), 458–462. https://doi.org/10.1136/archdischild-2019-318258

*Morin, K. L., Ganz, J. B., Gregori, E. V., Foster, M. J., Gerow, S. L., Genç-Tosun, D., & Hong, E. R. (2018). A systematic quality review of high-tech AAC interventions as an evidence-based practice. *Augmentative and Alternative Communication, 34*(2), 104–117. https://doi.org/10.1080/07434618.2018.1458900

*Odom, S. L., Thompson, J. L., Hedges, S., Boyd, B. A., Dykstra, J. R., Duda, M. A., … Bord, A. (2015). Technology-aided interventions and instruction for adolescents with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 45*(12), 3805–3819. https://doi.org/10.1007/s10803-014-2320-6

*Park, M. J., Kim, D. J., Lee, U., Na, E. J., & Jeon, H. J. (2019). A literature overview of virtual reality (VR) in treatment of psychiatric disorders: Recent advances and limitations. *Frontiers in Psychiatry, 10*, 505. https://doi.org/10.3389/fpsyt.2019.00505

Parsons, S., & Cobb, S. (2014). Reflections on the role of the 'users': Challenges in a multi-disciplinary context of learner-centred design for children on the autism spectrum. *International Journal of Research and Method in Education, 37*(4), 421–441. https://doi.org/10.1080/1743727X.2014.890584

Parsons, D., Wilson, N. J., Vaz, S., Lee, H., & Cordier, R. (2019). Appropriateness of the TOBY application, an iPad intervention for children with autism spectrum disorder: A thematic approach. *Journal of Autism and Developmental Disorders, 49*(10), 4053–4066. https://doi.org/10.1007/s10803-019-04115-9

*Pennisi, P., Tonacci, A., Tartarisco, G., Billeci, L., Ruta, L., Gangemi, S., & Pioggia, G. (2016). Autism and social robotics: A systematic review. *Autism Research, 9*(2), 165–183. https://doi.org/10.1002/aur.1527

Polisena, J., Castaldo, R., Ciani, O., Federici, C., Borsci, S., Ritrovato, M., … Pecchia, L. (2018). Health technology assessment methods guidelines for medical devices: How can we address the gaps? The international federation of medical and biological engineering perspective. *International Journal of Technology Assessment in Health Care, 34*(3), 276–289. https://doi.org/10.1017/S0266462318000314

Powell, C. (2003). The Delphi technique: Myths and realities. *Journal of Advanced Nursing, 41*(4), 376–382. https://doi.org/10.1046/j.1365-2648.2003.02537.x

*Powell, L., Parker, J., Harpin, V., & Mawson, S. (2019). Guideline development for technological interventions for children and young people to self-manage attention deficit hyperactivity disorder: Realist evaluation. *Journal of Medical Internet Research, 21*(4), Article e12831. https://doi.org/10.2196/12831

*Quezada, A., Juárez-Ramírez, R., Jiménez, S., Noriega, A. R., Inzunza, S., & Garza, A. A. (2017). Usability operations on touch mobile devices for users with autism. *Journal of Medical Systems, 41*(11), 1–11. https://doi.org/10.1007/s10916-017-0827-z

Richardson, K., Coeckelbergh, M., Wakunuma, K., Billing, E., Ziemke, T., Gomez, P., … Belpaeme, T. (2018). Robot enhanced therapy for children with autism (dream): A social model of autism. *IEEE Technology and Society Magazine, 37*(1), 30–39. https://doi.org/10.1109/MTS.2018.2795096

*Root, J. R., Stevenson, B. S., Davis, L. L., Geddes-Hall, J., & Test, D. W. (2017). Establishing computer-assisted instruction to teach academics to students with autism as an evidence-based practice. *Journal of Autism and Developmental Disorders, 47*(2), 275–284. https://doi.org/10.1007/s10803-016-2947-6

*Sandbank, M., Bottema-Beutel, K., Crowley, S., Cassidy, M., Dunham, K., Feldman, J. I., … Woynaroski, T. G. (2020). Project AIM: Autism intervention meta-analysis for studies of young children. *Psychological Bulletin, 146*(1), 1. https://doi.org/10.1037/bul0000215

*Scassellati, B., Admoni, H., & Matarić, M. (2012). Robots for use in autism research. *Annual Review of Biomedical Engineering, 14*, 275–294. https://doi.org/10.1146/annurev-bioeng-071811-150036

Tang, J. S., Falkmer, M., Chen, N. T., Bölte, S., & Girdler, S. (2019). Designing a serious game for youth with ASD: Perspectives from end-users and professionals. *Journal of Autism and Developmental Disorders, 49*(3), 978–995. https://doi.org/10.1007/s10803-018-3801-9

Trevelyan, E. G., & Robinson, N. (2015). Delphi methodology in health research: How to do it? *European Journal of Integrative Medicine, 7*(4), 423–428. https://doi.org/10.1016/j.eujim.2015.07.002

Valentine, A. Z., Brown, B. J., Groom, M. J., Young, E., Hollis, C., & Hall, C. L. (2020). A systematic review evaluating the implementation of technologies to assess, monitor and treat neurodevelopmental disorders: A map of the current evidence. *Clinical Psychology Review*. , Article 101870. https://doi.org/10.1016/j.cpr.2020.101870

Von der Gracht, H. (2012). Consensus measurement in Delphi studies: Review and implications for future quality assurance. *Technological Forecasting and Social Change, 79*(8), 1525–1536. https://doi.org/10.1016/j.techfore.2012.04.013

*Whyte, E. M., Smyth, J. M., & Scherf, K. S. (2015). Designing serious game interventions for individuals with autism. *Journal of Autism and Developmental Disorders, 45*(12), 3820–3831. https://doi.org/10.1007/s10803-014-2333-1

Wilkinson, K. M., & Madel, M. (2019). Eye tracking measures reveal how changes in the design of displays for augmentative and alternative communication influence visual search in individuals with down syndrome or autism spectrum disorder. *American Journal of Speech-Language Pathology, 28*(4), 1649–1658. https://doi.org/10.1044/2019_AJSLP-19-0006

Williams, P., Jamali, H. R., & Nicholas, D. (2006). Using ICT with people with special education needs: What the literature tells us. July. In *Aslib proceedings*. Emerald *Group Publishing* Limited. https://doi.org/10.1108/00012530610687704.

Xavier, J., & Cohen, D. (2020). Multidimensional impairments. *Handbook of Clinical Neurology, 174*, 159–169. https://doi.org/10.1016/B978-0-444-64148-9.00012-0. Elsevier.

*Zervogianni, V., Fletcher-Watson, S., Herrera, G., Goodwin, M., Pérez-Fuster, P., Brosnan, M., & Grynszpan, O. (2020). A framework of evidence-based practice for digital support, co-developed with and for the autism community. *Autism, 24*(6), 1411–1422. https://doi.org/10.1177/1362361319898331

# *Chapter 4: Have ICT design and research methodology improved over the last few decades?*

This question was the subject of an article submitted in 2023:

Grossard, C., Bettencourt, C., S. Anzalone, Chetouani, M., & Cohen, D. (2023). *Do information and communicative technologies research for neurodevelopmental disorders have improved overtime? A systematic meta-review*


## Abstract

**Background**: The significant increase of Information Communication Technologies (ICTs) use for individuals with Neurodevelopmental Disorders (NDD) has arisen the urgent need to examine numerical tools design and methodology implications.

**Methods**: We searched four databases (PubMed, IEEXplore, Scopus, and ACM Digital Library) to find relevant reviews on clinical applications of ICTs with individuals with NDD. We extracted all studies (n=1879) from 301 reviews, and classified them into categories: robots, serious games (SG), video modeling (VM), Alternative Augmentative Devices (AAC). We randomly assessed 182 studies (45 per ICT category) stratified by years of publication using the Connolly methodology scale and design ICT inventory (DICTI). We also described the best papers per ICT (most cited or highest impact factor journals).

**Results**: The overall quality of ICT studies is poor. SGs have the best methodological and design quality scores. Robots, AAC and VM studies' methodology have improved over the years, whereas only SG design quality has improved. Autism is the most prevalent NDD in terms of clinical focus, and no ICT is currently approved as prescription treatment in NDD, with the notable exception of EndeavorRx, a SG for Attention Deficit Hyperactivity Disorder (ADHD). From a qualitative perspective, the main features highlighted in the literature are reaching the standards of evidence-based medicine for research methodology, and personalization, adaptability, positive feedback, human interaction and affordability of the ICTs' design.

**Conclusion**: The review highlights the need for higher-quality studies, user-friendly technologies, personalization, positive feedback, and accessibility. ICTs are not detrimental tolearning and demonstrate potential benefits for individuals with NDD. However, more evidence- based studies are needed to reach treatment prescription recommendation.



**Keywords**: metareview, ICT, neurodevelopmental disorders, design, methodology

# *Introduction*

Neurodevelopmental disorders (NDD) are a group of conditions characterized by delays in developmental domains such as general cognition, social skills, communication skills, behavior, motor functioning, attention and executive functioning. These disorders start manifesting in early childhood, but diagnosis depends on developmental maturation and the expression of the full symptomatology. They result in mild to severe impairments in autonomy and social, academic and personal functioning. According to the earliest clinical expression, they include intellectual disability (ID), Autism Spectrum Disorder (ASD), communication disorders (CD) that show first symptoms during early childhood, and specific learning disorders (SLD), motor coordination disorders (MCD) and Attention Deficit/Hyperactivity Disorder (ADHD) that usually start later (American Psychiatric Association, 2015). The comorbidity between NDD is frequently high (Xavier et al., 2020). E.g. Saito et al. (2020) found that 88.5% of 5 years children with ASD have at least one co-existing NDD. This high ratio of co-occurring NDD reveals the need to consider all NDD when building tools or therapies for these populations.

The use of Information and Communicative Technologies (ICTs) has increased these last 20 years (Grossard et al., 2018). These technologies can be developed on a large variety of supports: computer, mobile devices like smartphone or tablet, screen, robots, but also wearable technologies as smartwatch, or virtual and augmentative reality. They can take multiple forms as app, serious games, assistive technologies, and immersive reality. They can target a wide range of skills or behaviors as social and communication skills, academic knowledge, sensory and motor skills, autonomy and inclusion, emotion regulation (Grynszpan et al., 2014; Boucenna et al., 2014; Valentine et al., 2020). They can be use diverse setting including care centers, schools or at home (Miguel Cruz et al., 2017, Khan et al., 2019). ICTs are generally well accepted by parents and professionals but also by children or adolescents with NDD (Valentine et al., 2020; Richardson et al., 2018). However, a few numbers of studies have targeted adult users (Valentine et al., 2020). Many reviews have been conducted in the field of ICTs in particular during the last 3 years (i.e. Hollis et al., 2017; Grossard et al., 2018; Khan et al., 2019; Moon 2019; Sandback, 2019; Sandgreen et al., 2020). However, many of them focus only on a specific NDD, often ASD, while the DSM-V reunites all NDD because they share some similar features (e.g. impact on neurodevelopment as a consequence of common cause or of a lack of opportunity to exercise fully the impacted domain). Moreover, the high rate of co-occurring NDD should be more

systematically taken into account in order to have results that can be generalizable to a large population. Other reviews have focused on specific ICTs such as robots (e.g. Miguel Cruz et al., 2017), virtual reality (e.g. Park et al., 2019), app (e.g. Neary & Schueller 2018.), web- based interventions (Khan et al., 2019). To our knowledge, only Valentine et al. (2020) have focused on all NDD and included the different technologies. However, their review only focuses on the effectiveness of the intervention and the impact of their implementation on user and cost. Yet, an important part to evaluate and help to improve the quality of ICTs research concerns design choices. Reviews on how to design ICT tools are less frequent, even if some authors have already proposed some framework (e.g., Khowaja et Salim, 2020; Whyte, 2015). However, frameworks are often proposed for a specific population, a specific ICT and specific targeted skills, which prevents them to be widely used.

Due to the increasing number of digital tools towards people with NDD (Miguel Cruz et al., 2017), the need to find an effective way to evaluate them becomes urgent. This is a particularly important question regarding the benefit and the cost of these solutions. Recently, the U.S. Food and Drug Administration (FDA) has granted clearance for EndeavorRx, an Akili's video game therapy for ADHD, which make it the first prescription treatment delivered through a video game (Canady, 2020; Kollins et al., 2020). In Germany, the Federal Institute for Drugs and Medical Devices has set up an assessment procedure in order to evaluate Digital Health Applications (https://www.bfarm.de/EN/MedicalDevices/DiGA/_node.html). Since December 2019, The Digital Healthcare Act introduced prescription of apps that are reimbursed by health insurers. In France, the government is currently supporting the creation of a Living and Learning Lab in order to help innovative project leaders to design technologies and services that are adapted to people with NDD and to evaluate new technologies as well as innovative educational and pedagogical methods used with people with (NDD) (https://www.lillabneurodev.fr/).

In this context, we conducted a systematic meta-review of the literature. We aimed to answer the following questions: (i) what are the main ICTs designed for healthcare of NDD? (ii) Does research has improved overtime in terms of experimental methodology quality and ICTdesign quality in studies focused on individuals with NDD? (iii) Based on the best publications according to citations or journal impact factors, are they some active components in ICTs that appear clinically relevant; and (iv) how are digital therapies included in the treatment of people with NDD?

# *Methods*

*Search procedure*

Between 8th and 11th December 2020, we performed a computerized search of the Medline (PubMed version), IEEXplore, Scopus and ACM Digital Library databases. The search used the following keywords: ("review" OR "metareview" OR "metaanalysis" OR "systematic review") AND ("neurodevelopmental disorder" OR "developmental disorder" OR "developmental disabilities" OR "autism" OR "developmental disorders" OR "dyslexia" OR "ADHD" OR "specific learning disorders" OR "communication disorders" OR "intellectual disability " OR "attention disorders") AND ("new technologies" OR "digital health" OR "eHealth" OR "technology based intervention" OR "technology" OR "technologies" OR "Information and communication technology" OR "ICT" OR "robot" OR "innovative technology" OR "serious games" OR "virtual reality" OR "computer"). We screened all identified reports, studies and reviews by reading the titles and abstracts. In addition, the references' lists of the studies that met the inclusion criteria were reviewed to identify additional studies for inclusion.

*Inclusion and exclusion criteria*

The reviews included in the analyses met the following criteria: (i) they made a review of the literature, whatever type of review (state of the art, systematic review, meta-analysis, meta-review) ; (ii) they reported on new technologies ; (iii) they targeted individuals with NDDs ; (iv) the papers were written in English. We included journals articles, book chapters, thesis and conferences proceedings. We excluded all papers about cerebral palsy and paper for those the diagnostic of the population were not clearly defined. Moreover, we excluded papers exclusively on sensor technologies as eyes or movement trackers, sleep assessment devices, as well as papers focusing on prothesis or orthosis. We also excluded Brain-Interface computer or neurofeedback technology and microswitch technology. Finally, we excluded all papers describing tools that are not directly in interaction with people with NDD: (i) telepractice tools; (ii) tools for data collection as fMRI, EEG...; (iii) devices dedicated to parents or clinician (as guidance, screening or diagnosis).

**Figure 1 summarizes the flowchart of the study. We ultimately found 301 reviews that corresponded to our criteria.**

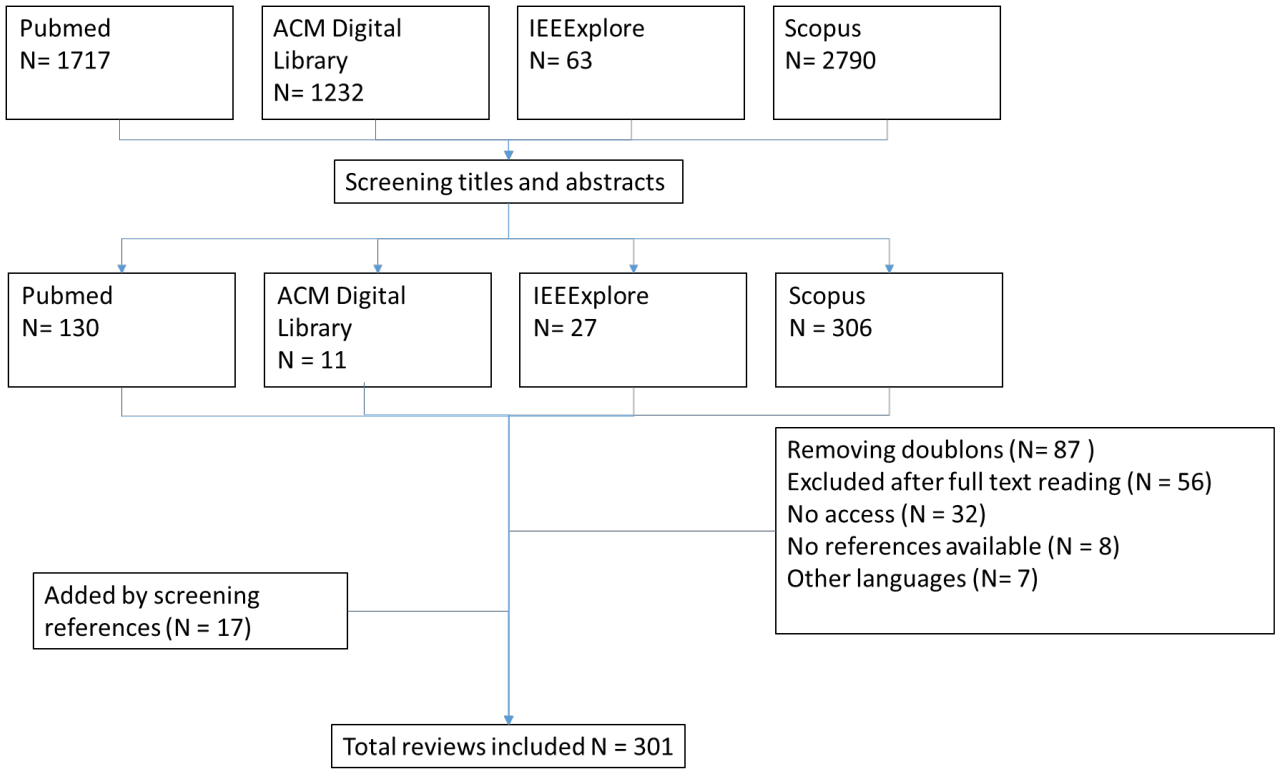



**Figure 1: Flowchart**

We extracted from the reviews all the studies in which at least one participant with NDD has tested the ICT. We used the same exclusion criteria as we did for the reviews. Furthermore, we excluded studies that did not involve a test with the targeted population (i.e., studies on technical development). We finally we created a database including 1879 studies.

Each study was then classified regarding the ICT used in the experiment in (i) Serious Games (SG) and apps, (ii) Video Modeling (VM), (iii) Augmentative and Alternative Communication (AAC), (iv) robots, or (v) other technologies (i.e.: reading tools, planners, DVDs or smart- objects).

*Assessment of experimental methodology and ICT design*

Given the number of studies, we decided to apply a random assessment of a subgroup of studies stratified by time and type of studies. We separated studies regarding the date of publication in 3 periods: until 2011, between 2012 and 2015 (included), after 2015 (excluded). This separation allows us to obtain an equivalent number of studies for each period. For each category SG, VM, AAC and Robots, we randomly picked 15 studies per period for a total of 45 studies per categories. For each group of 15 clinical trials, 5 were rated by judge 1, 5 were rated by judge 2 and 5 were rated by both judges. Both judges and authors are female; one is a psychologist and PhD student and the other is a speech therapist and research engineer, both researchers' work focus on ICTs and children with NDD. Judges rated each study regarding the quality of the experimental methodology and the quality of ICT design. One study in the category SG and one in the category Robot present two tools. We so rated each tool separately for their design for 46 observations in the SG and in the robot categories. We used the scale developed by Connolly et al. (2012) to assess the experimental methodology of each study. This scale includes five dimensions; each rated from 1 to 3, assessing the type of study (Randomized Control Trial vs. controlled study vs. study without control and case study), the possibility to generalize results, the description of the sample, the trust in the result and the protocol quality.

To assess the design variables, we used the Design ICT Inventory (DICTI, Grossard et al., 2023) assessing 13 features from 0 to 2 of the 4 main ICTs (AAC, VM, robot and SG): customization, feedback, rewards, contextualized learning, enhance motivation, manage difficulty, increasing accessibility, clarity of instruction and content, attention capacity, clear goals, minimalistic graphics and audio and human interaction. We assessed the ICT design based on the description available on the article from our database; therefore DICTI scores may vary for a same ICT from one study to another (especially for robot). In some cases (2 studies), we found no description of the features of the ICT (i.e., a study describing the skills worked in the task but not the features of the program itself) or how the ICT was using in the study (i.e., the study describing a robot do not describe how the robot was programmed for the intervention) and rated NDA (No description Available) that was considered as a score of 0 in the statistical analysis. When an Internet link or a reference describing the design of the ICT was given in the article, we looked directly in the on the Internet or the other article to find information about the design.

| ICT | ICC methodology scores | ICC design scores |
|---|---|---|
| All | 0.80 | 0.9 |
| VM | 0.65 | 0.94 |
| AAC | 0.79 | 0.75 |
| SG | 0.75 | 0.94 |
| Robots | 0.95 | 0.99 |

**Table 1. ICC for rating using the methodological scale and the design scale**

Inter rater agreement was assessed using intraclass correlation. They are summarized in table 1 (supplement material). Global ICC was considered good for the methodological scale ($ICC_{method}$= 0.80) and excellent for the design inventory ($ICC_{design}$=0.9). ICC are globally good for each type of ICT (ICC>0.75) except for the methodological score for video modeling who can be considered as acceptable ($ICC_{VMmethod}$=0.65).

*Description of the best papers according to ICT categories*

Given the number of studies, we decided to describe for each ICT the three most cited article from Google Scholar (in March 2023), as well as the 3 articles published in the highest impact factor journals according to the year of publication. In case of equality, 4 papers were described qualitatively.

## *Results*

### Distribution of selected studies across domain and time

Studies were published between 1968 (Colby, 1968) and 2021. We found 1879 studies on ICT used in NDD. Among them, 836 studies focus on SG, 276 focus on VM, 170 focus on AAC, 319 focus on robots and 268 focus on other technologies (Figure 1). Concerning the "other technologies", most of the studies focus on assistive technologies as reading tools, planners, or refers to specific technologies as DVDs or smart-objects. Skills targeted are social skills, academic skills, autonomy-independence (including vocational skills), communication, executive functioning, behavior (as anxiety or stereotypies) and motor skills. Scientific interest regarding

AAC and SG remained stable overtime, interest regarding VM decreased, whereas interest regarding robots slightly increased.

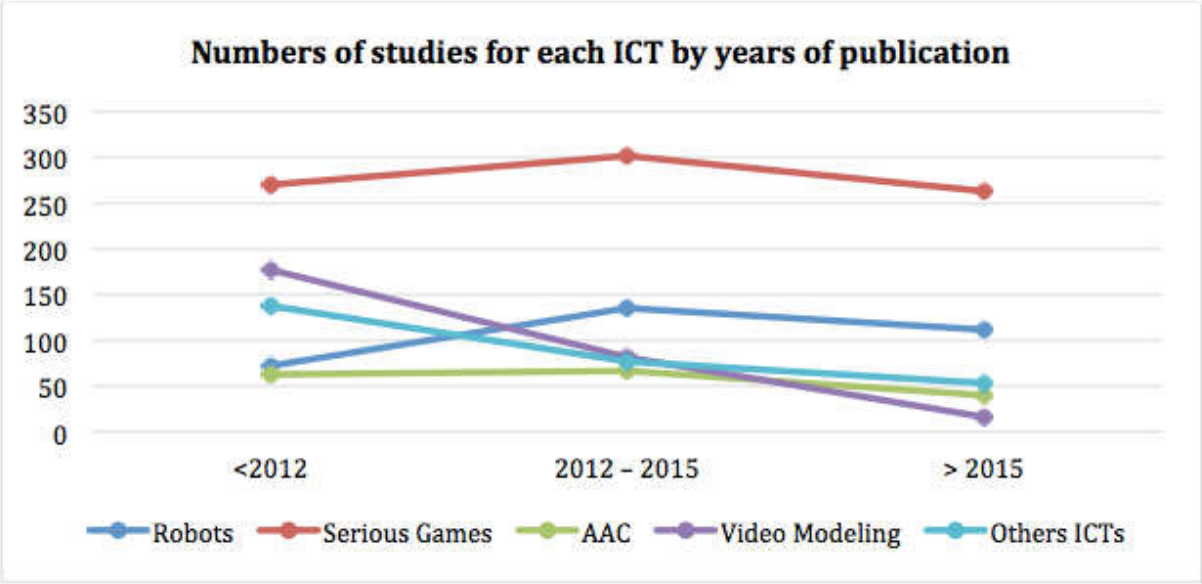



**Figure 2. Numbers of studies for each ICT by years of publication**

*Quality of experimental methodology overtime*

Experimental methodology quality of the studies varies significantly across the 4 ICT domains (SG: Mean=8.67, SD= 2.69; Robots: Mean= 7.74, SD=2.55, AAC: Mean= 7.41, SD=2.6; VM: Mean= 7.11, SD=1.5) , with a small advantage for SG (p= 0.011, Welch's ANOVA).. Scores for all ICT varies widely as all domains reach the minimum score for this scale (5/15) as the maximum score for AAC and almost the maximum score for SG, Robots and VM (14/15). These variations occur whatever the years of publication. However, when we assessed the impact of the year of publication on Connolly scores thanks to a Spearman correlation, it appears that scores globally increase with the year of publication. Regarding each ICT, this positive correlation is found for robots (p=0008), VM (p=0.027) and AAC (p=0.048) but not for SG (p=0.92) (see details in figure 3).

**Methodological quality (Connolly et al. 2012)**

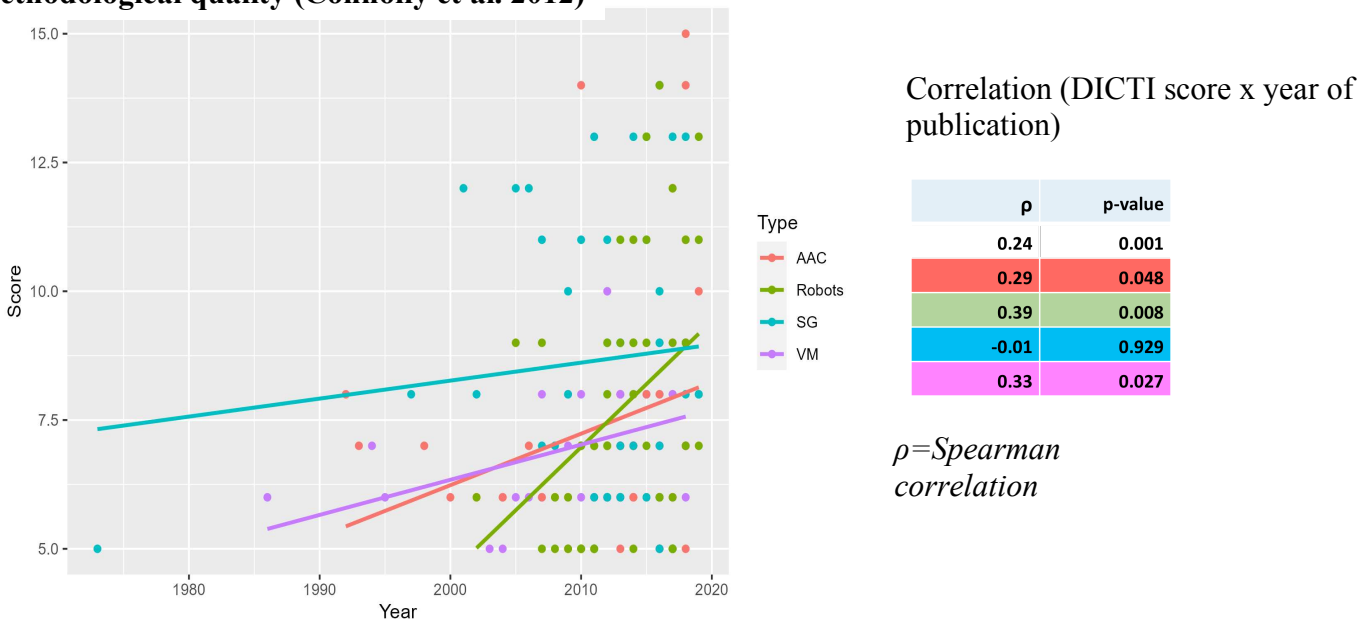
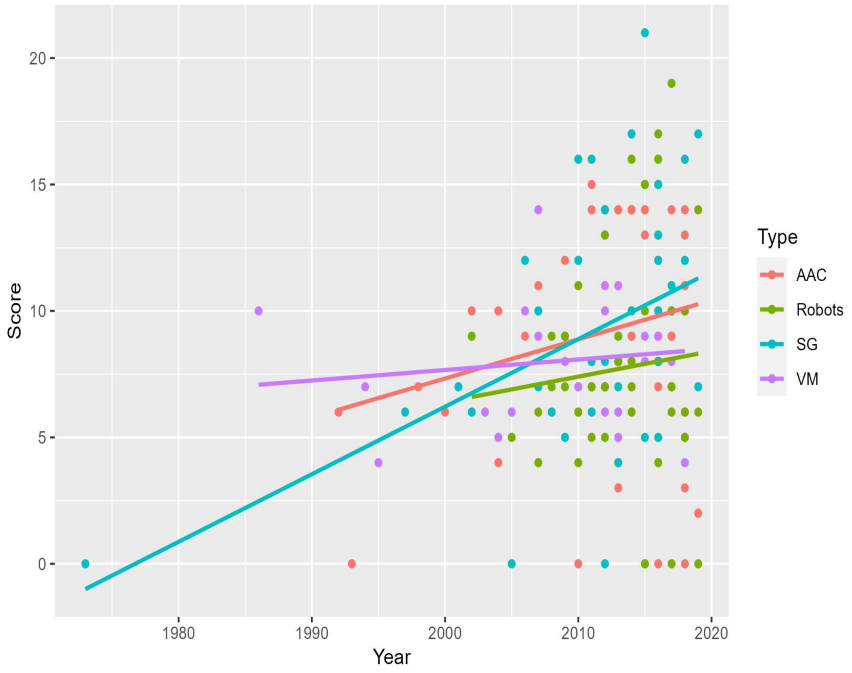



**Figure 3. Scores at the methodological quality scale (Connolly et al., 2012) by years of publication**

*Quality of design overtime*

Regarding design quality of the studies, scores are similar across the 4 ICT (Robot: Mean=7.72, SD=4.32); VM: Mean=8.13, SD=2.17; SG: Mean=9.29, SD=4.69; and AAC: Mean=9.15, SD=4.65). There is no significant difference between ICTs (p=0.216, Welch's ANOVA). Range scores for all ICT varies widely for Serious Games (from 0 to 21) and Robots (from 0 to 19). These variations are also presents for VM (from 4 to 14) and AAC (from 0 to 15). When we assessed the impact of year of publication on scores thanks to a Spearman correlation, it appears that scores globally increase with the year of publication. Regarding each ICT, this positive correlation is found for SG (p=0.003) but not for AAC (p=0.147), robots (p=0.537) and VM (p=0.407) (see details in figure 4).

**DICTI (Grossard et al., 2023)**




Correlation (DICTI score x year of publication)

| ρ | p-value |
|---|---|
| 0.23 | 0.002 |
| 0.22 | 0.147 |
| 0.09 | 0.537 |
| 0.44 | 0.003 |
| 0.13 | 0.407 |

*ρ=Spearman correlation*

**Figure 4. Scores at the design quality scale (Grossard et al., 2023) by years of publication**

*Main studies by domain according to citations and impact factors*

Tables 2 to 5 in the appendix summarize the three most cited article from Google Scholar as well as the 3 articles from the highest impact factor journals per domain, respectively robot, ACC, SG and VM. The experimental methodology and main results are described below.

We observed that (1) robotic studies have for the most part poor methodological quality, in particular small sample sizes, with the exception of random control trials (Kim et al., 2013; Kumazaki et al., 2018; Huskens et al., 2015). The targeted population is autistic individuals, and the primary targeted skills in these studies are social skills. The intensity and duration of interventions can vary, ranging from short interaction (Kumazaki et al., 2018; Kim et al., 2013) to longitudinal studies (Robins et al., 2005). The majority of the interventions are delivered by the researchers who are in charge of controlling the robot through the Wizard-of-Oz technique, a popular remote control in human-robot interactions (Steinfeld, Jenkins, & Scassellati, 2009), and only a small percentage of the robots are fully autonomous (Scassellati et al., 2018; Huskens et al., 2015). The articles highlight in particular the possibility of pre-programming the robot and its appealing physical characteristics. However, most studies pointed out the robots' design weaknesses, which include limited adaptability to autistic children's needs, restricted motions and verbal repertoire, and the need for technical assistance.

(2) The methodological quality of AAC studies is also generally poor, mainly consisting of case studies or small group studies without controls. The targeted population is ASD and ID individuals and the primary targeted skill is always communication. The interventions primarily involve speech-generated devices on iPads or applications. The person in charge of delivering the intervention includes speech-language pathologists and teachers. The articles highlight the accessibility and cost availability of devices such as iPads and apps, however most AACs require prior training.

(3) SG studies methodological quality is good, including controlled studies (Klingberg et al., 2002; Temple et al., 2013; Francheschini et al., 2013) or random control trials and large sample sizes (Klingberg et al., 2005; Golan & Baron-Cohen, 2006; de Vries et al., 2014) although we observed a lack of participants' characteristics description in some studies (Golan & Baron-Cohen, 2006). These studies are also the most cited from the 4 ICTs domains, ranging between 800 and 2700 citations. The targeted population can vary including individuals with

ADHD (Klingberg et al., 2002; Klingberg et al., 2005) learning disorders (e.g. dyslexia) (Temple et al., 2002), and ASD (Golan & Baron-Cohen, 2006; Serret al., 2014; de Vries et al., 2014). The duration of interventions can vary from 4 weeks to 15 weeks. The targeted skills are executive functions, reading skills, and social skills. The interventions are typically delivered by researchers or clinicians, and sometimes do not require adult supervision or facilitation. The design quality scores are also relatively high, with significant description of the gaming platform. Strengths include the games being related to social context and offering multiple feedbacks, while weaknesses in the design often includes the lack of multiplayer options and limited personalization. To date, EndeavorRx™, a SG for ADHD, is the only FDA approved prescription treatment delivered through a video game (Canady, 2020). It is not included in table 4 as the journal (The Lancet Digital Health) was too recent to reach a high impact factor (Kollins et al., 2020).

Finally, (4) VM methodology quality is poor, predominantly consisting of case studies, and small sample sizes. The duration of the intervention appears to be the most significant from the 4 ICTs and can vary from one-time a day exposition for three months (Spriggs, Knight & Sherrow, 2015) to three times a day for 25 sessions (Litras et al., 2010). The targeted populations are individuals with ASD and ID and the targeted skills include social skills, communication, and autonomy. Videotapes are commonly used as support for these types of interventions, which are delivered by researchers, therapists, or participants' parents. VM design is often poorly described. However, most studies emphasize the lack of ICT personalization (Charlop & Milstein, 1989; Charlop-Christy et al., 2000), and feedback (Horn et al., 2008; Spriggs et al., 2015).

## *Discussion*

In this review, we evaluated the methodological and design quality of a randomly selected group of 182 studies involving ICTs and NDD to assess digital technologies for health in NDD. By investigating these two main aspects in the creation of a digital therapeutics, we aimed to answer four questions that we will discuss in this section.

*How are ICTs evaluated in clinical studies?*

There is currently no standard framework for ICT assessments. Depending on the state of advancement of the research, there are different experimental phases. Feasibility and usability trials often take the form of case studies (Liu et al., 2017) or group studies without control (Bargagna et al., 2018), as the particular interest is on the feasible operation of the ICT. These studies often focus on the user's perception of the ICT, while usability studies mainly verify the usability of the ICT in terms of its adaptability (Nielsen et al., 1994; Serret et al., 2014; Zou et al., 2022). Gyori et al. (2015) proposed an initial phase involving neuro-typical individuals to improve their first ICT prototype, thereby avoiding any technical issues encountered when conducting a study with NDD participants. Indeed, it appears that even good conducted studies are not sufficient to users of digital technologies (Zervogianni et al. 2020). Users are also looking for other sources of empirical evidences as online review of other users or expert opinion. Finally, efficacy trials investigate the impact of the numerical intervention on individuals' outcomes. These studies have best quality in terms of experimental methodology, as they often are randomized control trials including a control group exposed to another settings (Kim et al., 2013; Duquette et al., 2008). Overall, studies improved their methodological assessment of ICT over the years. The scores of the methodological scale improved for VM, AAC and especially robots but not for SG. However, SG clinical trials appeared to have the best research methodology quality and VM had the lowest score on the methodological scale. To date only one single ICT, EndeavorRx™ SG has received a FDA approval in ADHD. In details, VM, AAC and robots mostly used case studies (e.g., VM: Horn et al., 2008; Litras et al., 2010; Spriggs et al., 2015; AAC: Reichle & Ward, 1985; Flores et al., 2012; Gevarter et al., 2014; robots: Robins et al., 2009; Pioggia et al., 2007; Kozima et al., 2007), whereas SG are for the most part evaluated in group studies (e.g., Serret et.al (2014). For VM and AAC, case studies improved progressively

with the use of multiple baselines becoming more and more frequent (e.g., VM: Charlop-Christy et al. (2000); Horn et al. (2008); AAC: Reichle & Ward (1985). For robots, the majority of old studies had not a clear assessment of their effect on people with NDD, and were only feasibility studies reporting how patients reacted to the robot (e.g., Jordan et al., 2012). Few recent studies assessed robot's impact on patient's skills thanks to automatic/learning algorithm and direct observations (e.g., Scassellati al., 2018). Few others include robots in a more naturalistic environment like classroom, which allows studying the effect of the robot on human-human interaction (Scassellati et al., 2012). The assessment of the quality of the studies differs across reviews. For example, Khan et al. (2019) based their assessment on the Critical Appraisal Checklist for RCTs ; Grossard at al. (2017) used a scale based on a work by Connolly et al. (2012); Ganz et al. (2017) used the adaptation by Maggin, Briesch and Chafouleas (cited by Ganz et al., 2017) of the basic design standards for single-case research proposed by What Works Clearinghouse (U.S. Department of education, 2016, cited by Ganz et al., 2017). Despite these differences in methodology, most authors concluded that there is a lack of high quality studies in the field of ICTs, whatever the form they take (Zervogianni et al., 2020; Miguel Cruz et al., 2017; Hollis et al., 2017; Morin et al., 2018). In our meta-review, the quality of methodology for all ICT remained poor, even for recent publications compared to the standard of medical assessment. Gradually more RCTs can be found in the literature, however, not all of them are well conducted (Khan et al., 2019; Grynszpan et al., 2014). Most meta-analysis focusing only on RCTs could not use all the studies they reviewed to make their analysis as a lot of studies did not fill all the quality criteria to allow an analysis (e.g.; Moon et al., 2019 kept only 2/7 studies; Khan et al. 2019 kept 5/10 studies). Khan et al. (2019) noted that most RCTs lack of blinding participants or blinding clinicians. Hollis et al. (2017) reported that parents tended to say their child improved but independent observers who are more likely to be blinded to the intervention found no difference. The comparator used in group studies are classically treatment as usual, other ICT or waiting list (see Khan, 2019).

Even if RCTs is the gold standard in clinical research and in the scale we used (Connolly et al., 2012), group studies or single cased studies can also correspond to Evidence Based Practice (Bennett, 2016; Morin et al., 2018; Root et al., 2017). Root et al. (2017) evaluated the quality of single case studies and group studies. From 29 studies included, only 10 of them where considered to have high or acceptable quality for the review.

The 10 studies selected provided sufficient proof to conclude that computer-assisted interventions meet the criteria of EBP in the field of teaching academics to children with ASD according to the National Technical Assistance Center on Transition criteria (2015, cited by Root, 2017). Finally, even if VM and AAC obtained the lowest methodological score in our review, they meet the standard for EBP in different reviews (Morien et al., 2018, Steinbrenner et al., 2020; Wong et al., 2015).

Another limitation is the difficulty to recruit large population (Parsons et al., 2019). Most studies have sample size under 10 participants and lack of information regarding participants characteristics (Root et al., 2017). Moreover, recruitments are very often realized in care centers (often just one), which focus on a targeted population in one geographical perimeter. Most studies explored only people without comorbidities (Grossard et al. 2017), which do not reflect the usual heterogeneity found in NDD (Xavier et al., 2020); for instance, in the field of autism, high-functioning populations are overrepresented (Grynszpan et al., 2014). These biases make it difficult to generalize the results (Grossard et al., 2017; Miguel Cruz et al., 2017; Pennisi et al. 2016). One solution to avoid these difficulties could be to develop technologies that could be easily used at home or in the child's environment like school setting. In this case, technologies must be affordable, easy to use and with technical support available.

*What are the main design features in digital technologies for NDD?*

Even if the number of design features increased for all ICT over the years, studies fail to treat design and efficiency equivalently. AAC, VM and Robot ICT did not improve DICTI score overtime, whereas SG improved it. However, SG was the only ICT in which the score at the methodological scale did not improve. Good studies describing design processes often proposed a very light assessment with the population targeted; conversely, good methodological studies often forget to describe accurately design features of the ICT. The need for personalization of digital technologies for users to engage them effectively reaches a consensus (robots: Huskens al., 2015; Scassellati al., 2018; SG: Gollan et al., 2006; VM: Charlop & Milstein, 1989; Charlop-Christy et al., 2000). Personalization can occur in several ways: visual design (i.e. personalization of a characters, colors or sounds); adaptation of exercise or content (i.e. exercise order, difficulty levels and length); or adaptive algorithms to follow users. Hollis et al. (2017) reported that users prefer tailored or personalized messages, such as generic messages using their names. Users may also be able to personalize small features

like gender and appearance of a « guide ». Allen et al. (2016) emphasize that personalization is crucial in therapeutic interventions to meet the patient needs. However, our review found limited studies on personalization. Among the four ICTs, the personalization feature is most explored on AAC devices, as it is an essential feature that allows to fit with the user's profile. Conversely, VM studies provided very few possibilities for user adaptation, as they are usually designed for specific contexts, populations, and cannot be modified by users. Robots and SG also offer limited options for personalization, such as sound modification or using the user's name. However, our review found that personalization in robot studies primarily focused on therapist adjustment, rather than adapting the robot's visual preference to the user (Boucenna et al., 2014). The case of robots is specific as often the visual aspect of the robot is predetermined and robot appearance has been chosen depending on the objectives of the training but also the possibility of actuation of the robots (Scassellati et al., 2012). Even when robots, like the Bioloid Robot could be assembled in various configurations like dinosaur or puppy, the study reported by Pennisi et al. (2016) only use its humanoid form. Similarly, studies did not discuss managing features like lights and sounds to align with user preferences.

The need for positive feedback and rewards to promote learning in children with NDD is now well established (Horn et al., 2008; Litras et al., 2010; Spriggs et al., 2015). This has been well identified in the field of serious games (Whyte et al., 2015). However, these two features do not appear in others ICTs. In addition, positive feedbacks are essential to help the user knowing when he is making the task correctly and maintain attention (Whyte et al., 2015). Most human-robot interactions happen through visual cues (screens), sounds or actions; however, papers do not describe in which way the reaction of the robots supports the targeted behavior awaiting. In assistive technologies, video modeling is often compared to video prompting to support autonomy in daily tasks, but no study focus on positive feedbacks and rewards to promote the realization of these tasks. In AAC, the reward or feedback is considered given by the interlocutor but not by the ICT. In studies on VM, the question of reward is never addressed.

The absence of human interaction in most technology-based intervention could limit the effectiveness of the intervention, especially when the targeted skills are social skills (Sandbank et al., 2019). Our meta-review confirmed this view, as very few studies we evaluated support interaction between the user and other human, off line or online. Virtual Reality is often based on multiplayer games when serious games or Apps or essentially solo player game. Whyte (2015)

supposed that the higher rate of generalization in VR could come from that difference. But this needs to be further explored.

Design features to support generalization are better addressed in ICTs and concern the importance of contextualized learning, accessibility, clarity of instructions and clarity of goals (Grossard et al., 2023). Most studies focus specifically on this point, as they are particularly relevant to assure that people with NDD will be able to use the ICT. Visual characteristics of a display like color or symbol arrangement have to be taken into account because it can facilitate or impede the use of the device (Liang et al., 2018). In a same way, motors skills may sometimes be underestimated, even when they are necessary to use a device (Quezada et al., 2017). For instance, Strickland et al. (2007) had to drop off the use of a joystick with 2 ASD children with moderate-level functioning.

Ethics are frequently documented considering that issues with privacy and security can arise with numerical tools (Schultz, 2005). Additionally, the perception of the ICT is also often discussed and presented in a section named “social validity”. This section is classically addressed through users, caregivers or teachers questionnaires. Social validity refers to the social importance and acceptability of treatment goals, procedures, and outcomes (Foster & Mash, 1999); its measures can provide essential data to both clinical and research agenda on evidence-based practices (Strain, Barton &Dunlap, 2012). In contrast, this feature is not used in robots or SG as there is no specific frame to address the question of the user’s perception of the ICT’s and it’s robustness. Indeed, there are major variations on the way it is assess for both.

Clinicians and professionals of NDD are frequently involved in the development of ICTs (Allen et al., 2016). They bring the knowledge on the disorders but also on the organization and needs of the institutions they are working for; in that way, they can help to build a tool that is accurate (Guard et al., 2019). But more and more studies concluded to the necessity to involve the patients and their families in the conception of ICTs. They can participate to the design of the tools, the content but also be involved in a feasibility study to make sure the tool is correctly designed for the population. As an example, many tools do not focus on motor skills but require some that can be challenging for people with NDD (Allen et al., 2016; Quezada et al. 2017). Including both professionals and users allow to take into account both their point of view that are often focused on different aspects of a tool; professionals are attached to the objectives and the content of the game when users are also looking into the personalization and gamification

aspects (Tang et al. 2019). This can be achieved through a multidisciplinary and user-centered design approach (Carlier, 2020). If the implication of people with NDD seems greatly improve the quality of the design of the tools, their participation can be challenging. In this review, we did not looked at how to help people to participate in the design but more and more studies address this question (for a review, see Benton & Johnson, 2015; Börjesson, Barendregt, Eriksson & Torgersson, 2015)

*How to promote learning with ICTs?*

Results regarding the effectiveness of ICTs are inconsistent throughout the literature (Hollis et al., 2017). It is especially difficult to draw and summarize conclusions, as studies, reviews and meta-analysis differ widely in their methodology. Some meta-analyses support the interest of ICTs for people with NDD (Grynszpan et al., 2014; Ganz et al., 2017). However, while digital training has shown improvements in some cases, most studies have found that ICTs are not more effective than traditional treatment (Khan, 2019). Still, there is evidence to suggest that ICTs are not detrimental to learning and may be preferred by individuals with ASD compared to traditional tools (Allen, Hartley and Cain, 2016).

However, these findings are not consistent across all ICTs and targeted skills. Pennisi et al. (2016) found that users with ASD often perform better with a robot than with a human, and certain ICTs such as VM may be effective for promoting autonomy skills (Waldman-Levi et al. 2019). The use of iPads can promote certain targeted skills like instrumental requests but not others such as spontaneous social communication (Allen, Hartley & Cain 2016). Similarly, Ganz et al. (2017) found the use of high-tech AAC effective but significantly better for the expression of needs than for social closeness. A large part of studies focusing on feedback in digital therapeutics emphasized the need for clarity to communicate to the user if he/she is correctly progressing in the current task. Studies reporting about negative feedback always advised against it, as it can bring frustration or act like a reinforcer for the uncorrect answer (Whyte, Smyth & Scherf, 2015, Strickland et al. 2007). Feedback must be clearly link to the user behavior to help the user engage with the ICTs (Feil-Seifer and Matarić, 2009).

A consensus in the literature found that most studies fail to demonstrate maintenance and generalization of the targeted skills outside the specific context of the game (Grynszpan et al., 2014; Hollis et al., 2017; Ganz et al. 2017). Combining serious games with other activities may

help with generalization (Whyte, 2015). In this way, Powell (2019) proposed downloadable gaming resources like quizzes, as a complementary form of work to digital therapeutic and educational interventions. The potential of digital health interventions is not fully utilized, which may contribute to the lack of clear advantages over traditional methods (Grossard et al., 2017). The active components of ICT tools are not well investigated (Hollis 2017). This question is more addressed with robots, for which most of the studies focus on the technological characteristics and their potential impact on their use in therapeutic and educative interventions (Miguel Cruz et al. 2017). But, Hollis (2017) raised an incomplete question regarding what works in therapy. More studies need to investigate this, as well as how to adapt ICTs for a targeted population and under what circumstance (Parson 2019 ; Powell 2019). As for any psychological therapy, treatment personalization is key, considering individual preferences, emotional states, and cognitive and motor skills (Stumpp & Sauer-Zavala, 2021). Developers should investigate the context in which their ICT works best and clearly define whom it is adapted for in terms of age, gender, cognitive abilities, and sensory preferences.

The challenge lies in ICTs being able to adapt to the user's emotional state and cognitive skills in real time. Automatic algorithms and responsive tools, especially in robots and SG, are being integrated to address this (Dalton, 2016). Engineers should now develop ICT that can automatically adapt difficulties, exercises, graphical design, and attention levels based on the player's responses and behavior.

*How are ICTs included in treatment plans for people with NDD?*

The use of ICTs in usual treatment of people with NDD is still unclear due to a lack of information about its use once the studies end. Few studies have included a longitudinal follow-up (Scassellati et al., 2012), which is important for understanding the user's motivation. Some studies, especially in robots, have only involved one single interaction with the user. However, children with NDD are sensitive to novel stimuli and repeated interactions are necessary to assess if the amount of exposure can significantly modify the response of the user (Scassellati et al., 2012).

The duration of exposition to an ICT varies widely between studies, with some lasting as little as 5 minutes per day and others lasting up to 2 hours per week (Khan, 2019). However, there is no consensus on the best duration for these interventions. Some studies have

recommended a specific duration without explaining how it was determined (Khan, 2019; Parsons 2019), but feedback from families using these tools suggests that the recommended duration may be too long for many children (Parsons 2019). It is also important to consider the time needed by professionals to adapt the ICT to each user, as this can impact the length of the treatment period and potentially bias the results (Gyori et al., 2015).

Interestingly, Grynszpan et al. (2014) found a negative correlation between intervention duration and effectiveness, possibly due to interventions requiring user autonomy. Khan (2019) found that few interventions are therapists assisted (4 studies among 10), highlighting the need for technical support. Different degree of help can be found: distancial contact, face to face point or exclusively therapist-delivered. In many cases, there is an important need for technical support (Khanet al., 2019; Gyori et al., 2015). This support is often available during the study, but it's required even after the study (Allen et al. 2016). ICT can be valuable resources when care centers are far, but users and parents still need supports in using and adapting to the technology, notably when facing behavioral problems while using the digital tool with their child (Parsons, 2019).

Behavioral problems can arise with ICT use, necessitating caution and limiting usage with automatic shutdowns (Zervogianni et al. 2020; Parson et al. 2019). New technologies are generally accepted, but parents' attitudes may change over time. In the study of Parson (2019) on the TOBY App, parents reported new behavioral difficulties related to the device (i.e. sleep disturbance, too much interest in the iPad and behavioral problems when needed to stop). Involvement of parents and users in the design development of the ICT can help address this.

Cost-effectiveness data on ICT is lacking (Hollis 2017). However, technologies must be affordable and accessible (Zervogianni et al, 2020). Some technologies are still too expensive as robots (Miguel Cruz et al., 2017) or AAC (Allen et al., 2016) to be purchased by care centers or low-income families. Tablets are often affordable but the price of the apps can be expensive (Allen et al., 2016). The use of games or apps that are not device-dependent allow to avoid cost and maximize accessibility (Dalton, 2016). However, it is important to evaluate the impact of a technologies compare to the cost. As an example, Strickland et al. (2007) conduct experiment in VR with and without headset and reports that they did not find significantly different results between the two conditions that could justify the greater cost of the headset.

ICT is not always the solution for everyone with NDD, as preferences vary across

individuals between ICT and paper-pencil condition or traditional picture exchange system (Allen, Hartley, & Cain, 2016; Lorah et al., 2015; El Zein et al., 2016. Allen, Ball & Guarino (2015) suggest that parents who own an Ipad are less positive about the use of an iPad for AAC than parents who do not own one.

## *Limitations*

We decided to give a large overview of the field of ICTs in NDD as comorbidities between NDD are frequent, and NDD share common features (American Psychiatric Association, 2015; Xavier et al., 2020). Nevertheless, all NDD do have specificities and they are not addressed in this review. Even if this paper highlights the need for personalization, it does not develop the specificity for each NDD. However, there are already reviews that focus on specific ICTs in a given NDD.

Another limitation is that we assessed each ICT separately with the DICTI. However, some studies use more than one type of ICT at a time. This is the case for some studies involving robots (for example Wainer et al., 2014) that also used collaborative games to support interaction between the patient and the robot. For this type of studies, we decided to assess the main ICT on which the paper focuses on.

A major limitation in our work is the lack of design description in a large part of studies. This lack of description happens in old but also recent studies. Of course, we were not able to try all ICT we reviewed and so we used the DICTI in another way that it was created for as the DICTI supposed the possibility to try the ICT. We encourage future studies to better describe the design features of the ICT since this field needs to improve for ICTs that are not SG.

## *Conclusion*

This meta-review emphasizes the necessity to develop standard methodologies to evaluate ICTs design and the type of clinical trials they are assessed in (feasibility, usability and efficacy studies). In this regard, we assessed the evolution over the last decades of ICTs' experimental methodology and design quality employed in digital technologies' interventions for individuals with NDD. The overall quality of ICT studies remains poor, but methodology quality has improved for robots, AAC, and VM compared to SG. There is a lack of high-quality studies in the field. User-friendly technologies and more high-quality studies are needed. From a design

perspective, we noted that SG design quality has improved the most over the last years, despite having being the studies with the poorest methodological quality. The main features highlighted in the literature are personalization, adaptability, positive feedback, and human interaction. Affordability and accessibility are also important to take into consideration, as some technologies are still too expensive for the public hospitals and low-income families. Additionally, therapist assistance, and technical support are also crucial. Involving clinicians, professionals, users, and their families in the design process is important to provide technologies that are well accepted by NDD individuals and their families. The literature on learning with ICTs is inconsistent, but there is no evidence that ICTs are detrimental to learning for individuals with NDD, despite the need for more evidence-based studies to reach treatment recommendation.

# *Chapter 5: Can social robots be included and beneficial in a social skills group for autistic children?*

This was question the subject of an article submitted in 2023:
C. Bettencourt, C. Grossard, M. Segretain, M. Bree, H. Pellerin, M. Chetouani, S. Anzalone, D. Cohen (2023) Investigating the feasibility and usability of the Wizard of Oz robotic interface R2C3 in social skills group for autistic children: an exploratory study.

**Abstract**

**Background**: Socially assistive robots (SARs) have been shown to be promising tools to help autistic children learn social skills, but their effect within groups remains unexplored. We aimed to investigate the use of the Rehabilitation Robotic Companion for Children and Caregivers (R2C3) robotic platform in the context of a social skills group (SSG) for autistic children.

**Methods:** Six autistic children between 6 and 11 years old were included in this exploratory study and were randomly exposed to two conditions, an active or inactive interface, over ten weeks. We monitored the Autism Diagnostic Observation Schedule-2 (ADOS-2) communication and social scores and the number of engagement initiations and responses to social requests after each session. We also qualitatively explored the feasibility and usability of the Wizard of Oz R2C3 in the SSG setting and evaluated the interface design using the Design ICT Inventory (DICTI).

**Results:** The robot did not hinder the effectiveness of the SSG, as evidenced by the participants' significant improvement in social skills. The use of R2C3 in active mode was successful and led to a marked increase in engagement interaction initiations but did not show a significant increase in responses to engagement interaction requests and ADOS-2 scores. Qualitatively, the robot promoted social openings in autistic children in the early sessions. The design of R2C3 posed some limitations. DICTI scores particularly emphasized the lack of personalization by the user and the inability to manage the complexity of the robot's behaviors or of the time lag between the Wizard of Oz control and the behavior execution (making the robot's reactions challenging to integrate into the group's conversations).

**Conclusion:** This exploratory study is promising as it suggests that the QT robot with R2C3 interface promotes social openings in autistic children. Future studies should delve deeper into this use with a better-suited interface and more participants.

**Keywords**: autism, social assistive robot, Wizard of Oz robotic interface, social skills, engagement.

**Trial registration:** IIQCASSGS, retrospectively registered on 07/03/2023

## *Introduction*

Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder characterized by deficits in social skills and communication, restricted interests, and repetitive behavior (APA, 2013). Social skills training is a vital component of autism treatment, which focuses on minimizing maladaptive behaviors and facilitating the development of favourable social behaviors. Moreover, it can facilitate the acquisition of conversational skills (initiating, maintaining, and closing verbal exchanges), emotional skills (perceiving and understanding emotions) and social-cognitive skills, such as theory of mind (Kruck et al., 2017). This can be done by teaching interpersonal skills to patients and promoting their generalization and maintenance (Baghdadli & Brisot-Dubois, 2011). Group-based psycho-social skills interventions are among the most commonly used methods to improve social skills in autistic youth (Gates, Kang & Lerner, 2017; Reichow, Steiner & Wolkmar, 2012). However, despite their prevalent use, their efficacy remains inconclusive due to a lack of rigorous, well-designed research (Reichow, Steiner & Wolkmar, 2012; McMahon, Vismara & Solomon, 2013) as well as inconsistency regarding a universal definition of social skills and adapted scales and differences in therapeutic implementations for the intensity and duration of treatment (Rao, Beidel & Murray, 2008). However, a recent meta-view showed that the efficacy of the social skills group (SSG) was supported by suggestive evidence for improving social communication deficits and overall ASD symptoms in school-aged children and adolescents (Gosling et al., 2022).

Furthermore, the field of socially assistive robotics (SARs) has significantly increased in therapeutic interventions for autistic children (Grossard et al., 2918). The primary function of SARs in autism therapy is to facilitate the development and generalization of social skills (Scassellati, Admoni & Matarić, 2012). According to Tisseron (2018), a social robot is capable of impacting the affective state of its human interlocutor and thus potentially modifying his or her behavior. A considerable amount of research has shown that SARs can have positive therapeutic outcomes in autistic children by promoting social skills development (Saleh, Hanapiah & Hashim, 2021; Scassellati et al., 2018; Sartorato, Przybylowski & Sarko, 2017) and attention while decreasing stereotypic behaviors (Tisseron & Tordo, 2018).

Despite the recent growth in research on SARs for ASD interventions, their use in the context of groups of autistic patients is still underdeveloped. Based on this observation, it seemed interesting to expand on the field by exploring the feasibility of using a robotic interface in a

group setting previously developed for children with dysgraphia (Zou et al., 2021). To this end, the present study involves the SAR 'QT' controlled through the Wizard of Oz R2C3 interface implemented in an SSG for autistic children. The Wizard of Oz paradigm allows the use of such platforms in unstructured scenarios, so the therapist is continuously in control of the robot's behaviors through teleoperation via a tablet (Tozadore et al., 2017; Rietz et al., 2021).

The purpose of this exploratory study is to qualitatively explore the feasibility and usability of the Wizard of Oz robotic R2C3 interface (Zou et al., 2022) on SSG dynamics and measure its effect on the engagement of children within the group under two conditions: an active interface and an inactive interface. The most frequently used definition in studies investigating engagement is found in Sidner et al. (2005) and describes engagement as "the process by which interactors start, maintain and end their perceived connection to each other during an interaction. It combines verbal communication and nonverbal behaviors, all of which support the perception of connectedness between interactors" (Oertel et al., 2020). The concept of engagement holds great significance in human–machine interaction as it not only aids in the design and implementation of interfaces but also facilitates the development of advanced interfaces that can adapt to users' needs (Anzalone et al., 2015).

As predicted by the literature (Gates et al., 2017), we expect that SSG will improve children's social skills as well their engagement within the group. Our exploratory hypotheses are as follows: (1) it is feasible to implement the R2C3 robotic interface in an SSG for autistic children, (2) the presence of the QT robot will positively impact children's engagement and will (3) improve children's social skills and decrease their maladaptive behaviors during the SSG sessions.

## *Methods*

### Study design

This is an exploratory feasibility study that implements the SAR QT with the Wizard of Oz R2C3 interface (Zou et al., 2021). The experiment corresponds to an intraparticipant design where each participant is exposed to both conditions (active and inactive R2C3 interface). The proposed activities are tailored to the abilities of each group of children. The primary variable of this study is children's engagement in the group. The study was approved by the local university ethics' committee (IIQCASSGS).

#### *Participants*

Participants were recruited from the children's outpatient unit of the Child and Adolescent Psychiatry Department at the Pitié-Salpêtrière Hospital. The inclusion criteria included an ASD diagnosis validated by the Autism Diagnostic Interview (ADI-R) (Rutter, Le Couteur & Lord, 2003) or the Autism Diagnostic Observational Scale (ADOS-2) (Lord et al., 2012), age 6 to 11 years, absence of SSG intervention in therapeutic care and consent of at least one of two legal representatives. The exclusion criteria included severe intellectual disability, multiple disabilities, major behavioral disorders, degenerative disease or other disease that could interfere with the evaluations planned during this study (e.g., known epilepsy and/or history of seizures). We recruited six participants and formed two social skills groups, taking into account the age of each participant. Group A included children from 9 years 6 months to 10 years 4 months, while Group B included children from 6 years 4 months to 8 years 7 months. The sample consisted of 4 girls and 2 boys. See Table 1 for the participants' characteristics.

## Table 1. Participants' characteristics

| **Participants** | | **n°1** | **n°2** | **n°3** | **n°4** | **n°5** | **n°6** |
|---|---|---|---|---|---|---|---|
| **Group** | | A | A | A | B | B | B |
| **Age (y/o)** | | 10.4 | 9.6 | 9.9 | 8.7 | 8.1 | 6.4 |
| **Gender** | | F | F | F | M | M | F |
| **ASD Diagnosis validated by ADI-R or ADOS-2** | | ADI-R com=15<br>ADIR soc=24<br>ADI-R rep=7 | ADI-R com=11<br>ADIR soc=28<br>ADI-R rep=7 | ADOS-2=14 | ADI-R com=4<br>ADIR soc=16<br>ADI-R rep=5 | ADI-R com=7<br>ADIR soc=11<br>ADI-R rep=5 | ADI-R com=13<br>ADIR soc=17<br>ADI-R rep=6 |
| **WISC-V scores (2021)** | **VCI** | N/A | N/A | 45 | 59 | N/A | N/A |
| | **VSI** | | 75 | 63 | 69 | | |
| | **FRI** | | 75 | 49 | N/A | | |
| | **WMI** | | N/A | 54 | N/A | | |
| | **PSI** | | N/A | N/A | 49 | | |
| **Comorbid disorders** | | Communication and oral language disorder | Communication and oral language disorder | ADHD | Speech, writing, communication and oral disorder | Communication and oral language disorder | Communication and oral language disorder |
| **Additional clinical information** | | Delayed language acquisition; good nonverbal skills (imitation, pointing); uses pictograms. | Needs support for comprehension; can express her own emotions but needs support to better understand other people's reactions and emotional states. | Good communication skills but difficulty processing information; needs pictograms and support for comprehension. | Pictograms are essential to comprehension; needs adult' support; sensitive to failure and to positive reinforcement. | Delayed language acquisition; memory difficulties; behavioral problems; can express emotions; some emotional instability; stereotypical behaviors; restricted interests due to atypical sensory processing. | Deficient language skills; echolalia; reduced verbal comprehension; needs pictograms for comprehension; difficulties interacting with others, with transitions and joint attention; stereotypical behaviors. |

| | | | | | | |
|---|---|---|---|---|---|---|
| **SSG therapeutic goals** | Support and develop verbal demands, practice turn taking, develop social skills, practice emotional regulation. | Support and develop verbal demands, practice theory of mind and identify other's emotional states. | Practice sharing and honing conversational skills, practice emotional regulation, turn taking and imitation skills. | Support and develop verbal demands, practice emotion recognition and theory of mind, practice sharing, conversational skills and turn taking. | Support and develop verbal demands, practice emotion regulation and hone conversational skills. | Support and develop verbal demands, practice imitation, joint attention, sharing and turn taking. |

ADI-R Com= ADI-R score for language and communication (cut off 7); ADI-R Soc= ADI-R score for reciprocal social interaction (cut off 10); ADI-R Com= ADI-R score for restricted, repetitive and stereotyped behaviors and interests (cut off 3); ADOS-2= ADOS-2 scores for autism spectrum (cut off based on age >8); VCI= Verbal comprehension index; VSI= Visual spatial index; FRI= Fluid reasoning index; WMI= Working memory index; PSI= Processing speed index; N/A= not available; SSG= social skills group

## Materials

### The socially assistive robot QT

The SAR used during this study was QT, a humanoid robot developed by LuxAI that helps autistic children practice social and engagement skills (Bettencourt et al., 2022). Two studies have highlighted the effectiveness of using this robot to decrease stereotypic behaviors and improve social skills in autistic patients (Puglisi, et al., 2022).

*The R2C3 interface*

The Wizard of Oz R2C3 interface (Zou et al., 2022) was created as part of the iRecheck project, which combines a robot and a serious game-based approach to handwriting rehabilitation for children with dysgraphia (Zou et al., 2021). The interface contains 120 different behaviors classified into 33 menus according to their use. In the interface layout, there is a login page as well as a control page. The login page collects the name of one participant, which can be included in some pre-programmed behaviors, facilitating the personalization of the robot-child interaction. The control page includes the 33 menus in two tabs: the scenario and game tab and the reaction tab (see supplementary material). To investigate the feasibility of the R2C3 interface features on the engagement and social behaviors of children during the SSG, QT is present in each session but is used in two different ways. During half of the sessions, the R2C3 interface is inactive and does not display verbal and nonverbal social behaviors other than eye blinking. During the other half of the sessions, the interface is actively used. We used the Wizard of Oz paradigm, a human remote control of the robot, a popular design paradigm in human-robot interaction research (Steinfeld, Jenkins & Scassellati, 2009), which allowed the therapist to display specific wanted verbal behaviors. The order in which the active or inactive conditions were implemented was randomized. Among the set of behaviors proposed by the interface, we used only the categories adapted to the context of the group (Table 2).

**Table 2: R2C3 interface behaviors examples (Zou et al., 2022)**

| Category | Description | Examples |
|---|---|---|
| Positive reinforcement | The robot congratulates the participant. | “Bravo”, “Well done”, “So nice”, “Congratulations” |
| Encouragement when facing difficulties | The robot comments on the participant’s productions and encourages the participant to try again. | “Do your best”, “Breathe”, “I see you’re trying”, “Try again, you can do it” |
| Emotion recognition | The robot draws the participant’s attention to his or her emotions. | “You look happy”, “You feel bad?”, “You look angry”, “You look tired” |
| Interactions based on QT’s opinion | The robot expresses a personal opinion and questions the participant. | “Hello, my name is QT, what is your name?”, “Hello”, “Goodbye”, “Yes”, “No”, “Can you repeat”, “I don’t know, how about you?”, “Why?”, “It’s hard, can you explain?” |

## Procedure

### Experimental setup

The study took place in the research laboratory located at the child psychiatry department of the hospital. All sessions were filmed with three cameras from three different points of view (front, right, left) to obtain a good angle for each participant. Parental consent for video recordings was collected before the study. The experimentation room was set up in the same way for both groups (see images in the supplementary material). It included a children's table in the centre of the room, a chair for each participant and two chairs for the experimenters in charge of leading the group. The third experimenter was located in the back of the room and was in charge of controlling the robot with a tablet through the Wizard of Oz paradigm.

A whiteboard was used to present the visual schedule and take attendance (name labels and photographs of the children and experimenters and two photos of QT, one awake and one asleep, to illustrate the two robotic conditions). The robot was placed facing the participants next to the board.

*Structure of the sessions*

The sessions took place once a week in the early afternoon and lasted 30 minutes. We performed an introductory session before beginning the study so that the children could become acquainted with the experimenters and the robot and familiarize themselves with the room. This welcome session also aimed to gauge the level of each group in terms of comprehension, expression, behavior and social skills. Sessions were then spread out over 10 weeks.

During the sessions where QT was active, he was primarily a positive reinforcer for the children; he praised and encouraged them. He could also interact with them by greeting them at the beginning of the session and saying goodbye as well as questioning them ("What about you?", "Why?") and answering closed-ended questions ("Yes", "No", "I do not know"). During the sessions when QT was inactive, the experimenters explained to the children that the robot was tired and would only watch the session. To make it easier for the children to accept this idea, the experimenters had QT say, "I'm sorry, I'm tired" at the beginning of the session.

The sessions followed Ozonoff and Konstantareas' recommendations for social skills groups (Baghdadli & Brisot-Dubois, 2011). First, the groups were organized around a structured and predictable framework, and the sessions always took place in the same way (Table 3). A

timetable in the form of pictograms was presented to the children at the beginning of each session and remained posted so that the experimenters could refer to it throughout the session. Moreover, the proposed activities were adapted to the age and verbal level of the children. Thus, the difficulty levels of the games were not the same in the two groups. Similarly, the use of visual aids (pictograms, drawings, photographs) was systematic to support the children's understanding. Finally, the objectives for each session were progressive. All activities proposed during the 10 sessions are detailed in the supplementary material.

**Table 3: Framework of the sessions, therapeutic objectives and robot's purpose**

| Activities | | Objectives | QT's purpose |
|---|---|---|---|
| #1 | Introductory ritual:<br>Presentation of the schedule<br>Who is present?: each participant gives his or her first name and puts his or her picture on the board<br>How does QT feel today?: the children ask QT to determine whether he is feeling "sleepy" or is active | Facilitate transition to group<br>Structure the session<br>Practice turn taking<br>Joint attention | Say hello<br>Introduce himself<br>Share how he feels at that moment. |
| #2 | Physical or musical activity:<br>Imitate a rhythm or sound, imitate a gesture | Imitation<br>Practice turn taking | Encourage<br>Congratulate |
| #3 | Psycho-emotional activity:<br>Identify different emotions from the images in social stories, make sense of an emotion by imitating a facial expression, evoke situations related to a specific emotion | Recognition of emotions<br>Imitation<br>Joint attention | Encourage<br>Congratulate<br>Identify emotions<br>Ask for children's explanations |
| #4 | Activity around preferences:<br>Based on different themes, such as sports, foods, and animals, the children use pictograms to discuss their preferences and ask others | Sharing something personal<br>Practice turn taking<br>Joint attention<br>Practice conversational skills | Encourage<br>Congratulate<br>Ask for explanations<br>Answer questions about his own preferences |

**Outcome measures**

**Clinical measures**

Social and communicative skills, as well as adapted and maladaptive behaviors, were measured directly after each session using the Autism Diagnostic Observation Scale (ADOS-2) module 1 (Lord et al., 2012). The ADOS scores are organized into five domains: "A. Language and Communication", "B. Reciprocal Social Interaction", "C. Play", "D. Stereotypical Behaviors and Restricted Interests" and "E. Other Abnormal Behaviors". For this study, the domain "C. Play" was not included because the games included in the ADOS were not used in the groups.

There is currently no scale available to measure the rate of children's engagement in a group setting. Studies on engagement have thus far focused on engagement in a dual situation (a child towards a robot), notably via metric measures (e.g., movement tracking) (Anzalone et al., 2015). The rate of engagement was therefore measured by the number of times the child initiated a social interaction and the number of times the child responded to a social interaction. These social initiations and responses to social interaction requests could be verbal or nonverbal (phrases, single words, gestures, joint attention, etc.) and could be directed to QT, the adult, or another child. These data were counted for the same preference activity (described later) performed in each session. To limit bias, this activity was always presented in the same way and lasted the same amount of time (10 minutes). This rating was obtained based on the sessions' video recordings. At the end of each session, each experimenter was randomly assigned to rate the engagement scores of one of the participants. Qualitative ratings were also included at the end of each session in the form of clinical observation summaries.

*Design assessment of the robotic interface using the Design ICT Inventory (DICTI)*

The design of the R2C3 interface combined with the SAR QT was evaluated by the three experimenters using the Design ICT Inventory (DICTI) (Grossard et al., 2023). DICTI provides an easy tool to assess the design of ICTs, including robots, serious games (SG) and apps, augmentative alternative communication devices (AAC) and video modelling (VM). The endorsement of the trans-technology inventory was carried out through a Delphi study [27] involving a panel of 12 experts in ICT. Consensus and agreement were achieved after two rounds of feedback for each of the 13 items of the inventory: customization; feedback; rewards; contextualized learning; enhanced motivation; managing difficulty; increasing accessibility;

clarity of instruction and content; attention capacity; clear goals; minimalistic graphics and audio; human interaction; and trustworthiness. Each item was rated using a Likert scale: 0 (absence), 1 (partially considered) and 2 (fully considered) (Grossard et al., 2023).

*Statistical methods*

The statistical analyses were conducted using R 4.2.2 software using bilateral tests with a 5% level of significance. First, we described the sample of participants. The distribution of the quantitative variables was summarized using the mean and standard deviation. The distribution of the qualitative variables was reported as a number and percentage of occurrence for each level. Next, we sought to assess whether the activation of R2C3 had an average effect on the QT SAR and engagement scores. A Poisson mixed effects regression model was run for each score (package "lme4"). The model formula was "Score ~ QT + (1|Subject)". The subject was specified as ordered at random origin, and the absence of overdispersion was checked by the "performance" package. The independence between the session number and the presence of QT was controlled by the experimental design. Finally, the average evolution of scores across sessions was modelled using the same method. The formula of the models was as follows: "Score ~ Session number + (1|Subject)".

## *Results*

### The social skills group

The presence of the QT robot did not prevent or disrupt the social skills group according to plan. All predicted sessions could be performed with the corresponding duration. The clinicians conducted all the sessions on their own without an expert technician present, and no technical malfunctions were experienced during the entire study period. The control of QT's behaviors by the Wizard of Oz R2C3 interface was fluent enough to allow adequate group dynamics. The presence of QT did not affect the impact of SSG on participants, who showed a significant improvement in social skills after the ten group sessions on ADOS-2 scores for modules A (Language and Communication) and B (Reciprocal Social Interactions) of the ADOS-2 scale (Figure 1a). Scores on modules A and B both decreased significantly by a factor of 0.959 ($p = 0.028$ *) and 0.936 ($p < 0.001$ *), respectively, with each new session. The SSG also increased children's engagement in the group. The number of responses to social interaction requests increased significantly ($p < .001$*) by a factor of 1.061 with each new session. In

contrast, the number of social engagement initiations did not increase significantly across sessions (p = 0.06) (Table 4, Figure 1b).

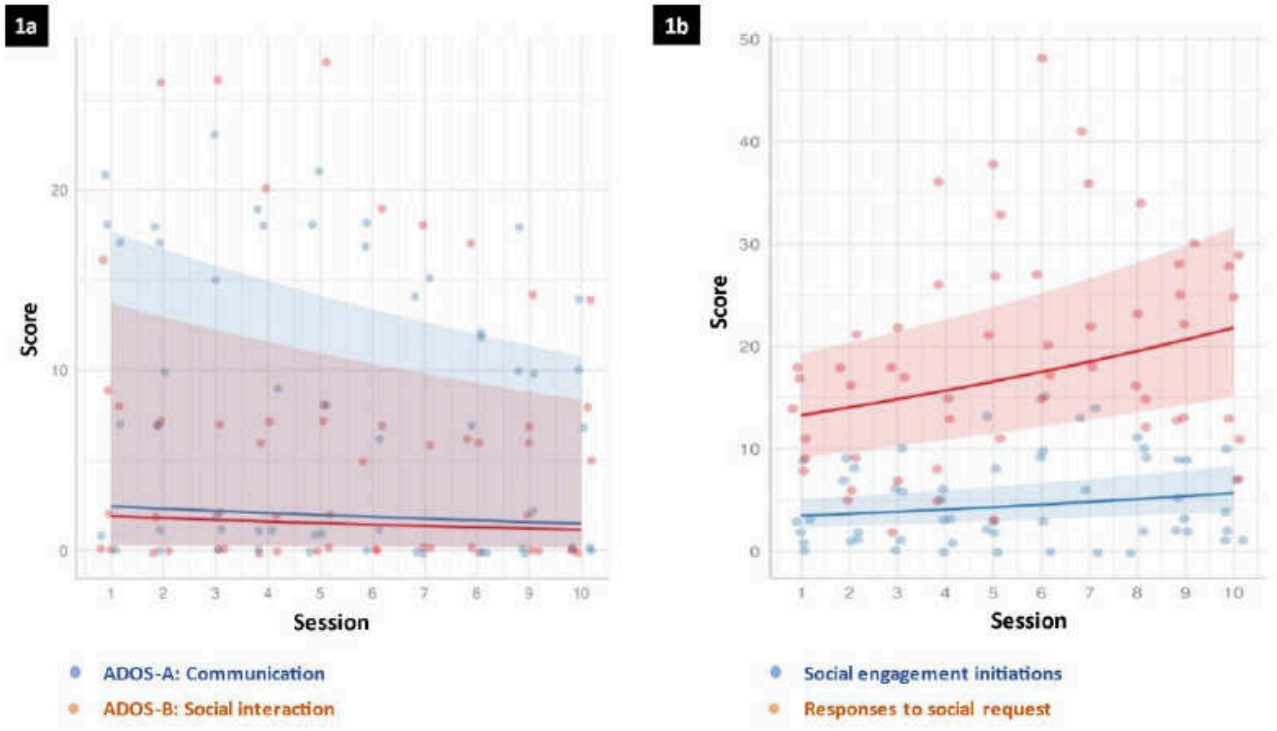



**Figure 1: Average evolution of ADOS-2 scores for modules A (language and communication) and B (reciprocal social interaction) (1a) and average change in engagement initiation scores and number of responses to social requests (1b) across the sessions**

**Table 4: Results of the effect of the sessions on the ADOS module scores and engagement rates**

| *Sessions effect* | | | | | |
|---|---|---|---|---|---|
| Score | Estimate | exp (Estimate) | Stf. Error | z value | Pr (>\|z\|) |
| ADOS_A communication | 0.042 | **0.959** | 0.019 | -2.195 | **0.028** |
| ADOS_B social interaction | 0.066 | **0.036** | 0.017 | -3.937 | **0.000** |
| ADOS_D restricted interests | 0.215 | **0.806** | 0.057 | -3.776 | **0.000** |
| ADOS_E abnormal behaviors | 0.047 | 0.954 | 0.032 | -1.498 | 0.134 |
| Responses to social requests | 0.059 | **1.061** | 0.011 | 5.606 | **0.000** |
| Social engagement initiations | 0.038 | **1.039** | 0.021 | 1.851 | 0.064 |

*Impact of QT and R2C3 during the sessions*

The presence of the QT robot had a positive impact on children's engagement in the SSG. We modeled children's number of social engagement initiations and responses to social interaction requests during the same activity and time frame of the sessions according to whether R2C3 was active (Table 5). The number of responses to social interaction requests was not significantly different ($p = 0.62$), but the number of engagement initiations was significantly different by a factor of 1.31 ($p = 0.03$) when the R2C3 interface was active. We also noted that the number of social initiations when the robot was active varied strongly from one child to another (Figure 2). For instance, for child n°4, the difference was more important when QT was active (delta = 6.75), whereas for child n°3, the social initiations were more important when QT was inactive (delta = -2). For the other four participants, the number of social initiations was higher when QT was active, but the difference was smaller than that for child n°4.

The activation of R2C3 with the QT social robot also did not improve children's social skills during each session group as measured by ADOS-2 scores on modules A (Language and Communication) and B (Reciprocal Social Interactions) for each session. Similarly, the activation of R2C3 did not improve children's negative behaviors as measured by ADOS-2 scores on modules D (Stereotypic Behaviors and Restricted Interests) and E (Other Abnormal Behaviors) (Table 5).

**Table 5: Impact of the robot's active condition on ADOS-2 scores and engagement rates**

| Variable | Estimate | exp (Estimate) | Std. Error | z value | Pr (<\|z\|) |
|---|---|---|---|---|---|
| ADOS_A communication | 0.01 | 1.01 | 0.11 | 0.09 | 0.93 |
| ADOS_B social interaction | -0.08 | 0.92 | 0.1 | -0.87 | 0.39 |
| ADOS_D restricted interests | -0.25 | 0.78 | 0.3 | -0.85 | 0.40 |
| ADOS_E abnormal behaviors | -0.14 | 0.87 | 0.18 | -0.76 | 0.45 |
| Responses to social requests | -0.03 | 0.97 | 0.06 | -0.50 | 0.62 |
| Social engagement initiations | 0.27 | **1.31** | 0.12 | 2.24 | **0.03** |

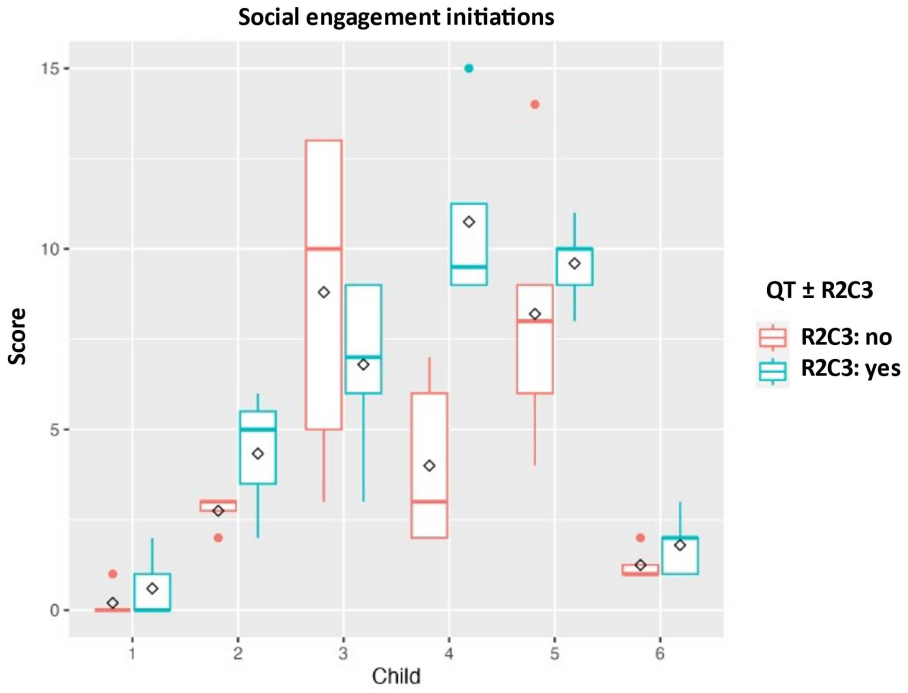



**Figure 2: Distribution of engagement initiation scores according to the active or inactive condition of R2C3. The diamonds correspond to the means of the initiation scores. The red boxes correspond to the sessions where QT is "tired", and the blue boxes correspond to the sessions where it is active.**

### Assessing the design of R2C3

The design of R2C3 (combined with QT) was evaluated post intervention using the DICTI (Grossard et al., 2023). As shown in Table 6, the total score was 15, for a maximum of 26. We observed several positive points: the interface was very easy to use even for nontechnological people, the positive reinforcements were varied and adapted, and the appearance and reactions of QT made it attractive and engaging. However, there was no possibility of customizing the interface to adapt to different profiles or of managing complexity (e.g., by adapting scaffolding according to the scenario and user capacities—i.e., the robot can first initiate the interaction, then just support it—or by modifying the speed of displaying the stimuli). Additional qualitative comments will be presented in the discussion.

**Table 6: R2C3 and QT robot design score according to the "Design ICT Inventory" (Grossard et al., 2023)**

| Item | Rating |
|---|---|
| 1) possible customization by the user | **0** : no personalization |
| 2) feedback | **1** : feedback that is clearly related to a goal |
| 3) rewards | **2** : rewards like objects, video, songs |
| 4) contextualized learning | **2** : clear link between scenario and user |
| 5) enhance motivation | **2** : fully considered |
| 6) manage difficulty or complexity | **0** : no difference between levels |
| 7) increasing accessibility: simplicity of use and autonomy | **2** : easy to use and usually accessible |
| 8) clarity of the instructions and content | **2** : visually and language adapted |
| 9) attention capacity | **1** : adaptation of duration or stimuli to keep the user engaged |
| 10) clear steps or goals for short and long term | **0** : none |
| 11) easy to process and modify graphics and audio | **0** : none |
| 12) human interaction | **1** : exchange with one person |
| 13) trustworthy | **2** : fully considered |

## *Discussion*

### The social skills group

We expected that the SSG would improve some of the children's social skills (Gates et al., 2017; Gosling et al., 2022). The results support the effectiveness of SSG interventions. Qualitatively, we were able to observe a real benefit of the sessions on the social skills of the children within the group. These observations are consistent with the literature on SSG for autistic children (Kruck et al., 2017; Bohlander, Orlich & Varley, 2012). As the sessions progressed, the children produced more social openings for adults and other participants, whereas in the first few sessions, there was no interaction between the children and few responses to the adults' social interaction requests. We also observed an improvement in role-taking skills. We believe that the recommendations for SSG (Baghdadli & Brisot-Dubois, 2011) in this study help to explain the improvements observed. However, the improvement of social interactions between the children can also be explained by the researchers' progressive adaptation of activities to the participants' cognitive and language levels. This was the case for the emotion recognition activity. At first, we asked the children to describe and interpret images, which was difficult for a certain number of the children and not playful enough to truly involve them in the activity. We then transitioned to a symbolic game using puppets, where the adults simulated problematic social situations (e.g., jealousy, frustration, sickness). This allowed all children to participate and to interact with each other through the puppets ("Are you okay, Grandpa?", "Are you sick, Mickey?", "Can we share?", "It's ok to feel hurt"). Finally, beyond the improvement of social skills, this group was reported to be a real moment of pleasure for the children. All participants came to the sessions enthusiastically, and the hospital care team told us on several occasions of the participants' fondness for the group and QT. Overall, this positive outcome is in line with studies that reported positive therapeutic outcomes with SAR in autistic children by promoting social skills (Saleh, Hanapiah & Hashim, 2021; Scassellati et al., 2018; Sartorato, Przybylowski & Sarko, 2017).

#### *Feasibility and usability of the R2C3 interface and SAR QT*

Our observations revealed that the feasibility and usability of the R2C3 interface and SAR QT within an SSG for autistic children was good overall. The inclusion of the robot in the group elicited positive reactions and engagement towards the intervention from the children,

which facilitated their social interactions and communication skills (Scassellati, Admoni & Matarić, 2012). Additionally, the robot's attractive humanoid allure provided a nonthreatening and consistent presence that led to increased motivation and participation in the SSG sessions (Robins, Dautenhahn, & Dubowski, 2009). We primarily used the positive reinforcement behaviors of R2C3. By doing so, we were able to position QT as a positive reinforcer that complemented the role of the therapists during the sessions (Kim et al., 2013).

From a usability standpoint, the interface was very simple to use even for nontechnological people. The clinicians conducted all the sessions on their own after prior training on how to use the Wizard of Oz R2C3 platform, which consisted of learning how to connect the interface to the robot through shared Wi-Fi, exploring the platform and the different menus and finally experimenting with launching the robotic behaviors during made-up scenarios. This confirmed the usefulness of the Wizard of Oz paradigm for human machine interaction (Tozadore et al., 2017; Rietz et al., 2021).

*R2C3 exploratory hypothesis on children's engagement*

The second main experimental objective was to explore whether the active condition of the QT robot using R2C3 had an impact on children's engagement during SSG. Social interaction initiations were significantly higher when QT was active, meaning that using the robot with the R2C3 interface promoted social opening in autistic children. This result can be explained in part by the novelty effect and strong interest that QT aroused in the children during the first sessions (Leite et al., 2009; Sung, Christensen & Grinter, 2009). At the beginning of the study, the patients were very receptive to QT's positive reinforcement and reacted positively to each new intervention (looks, smiles, laughter). It is likely that this enthusiasm for QT motivated the children to invest in the group from the beginning and to continue to enjoy the sessions throughout the study. At the beginning of each session, they wanted QT to be "awake" (in response to the question, "How is QT today?", the children answered "Good!"; during the session, some children asked him, "QT, you are awake?") and could express their disappointment if the robot was inactive. In addition, according to the hospital caregivers, the children talked about QT outside the group by specifying his state during the session, either tired or awake. This attraction to QT persisted even after the children understood that it was controlled by the adult via a tablet ("You told QT to say that"). Until the end of the experiment, the patients

enthusiastically mentioned QT before going to the group. However, in view of the heterogeneous results obtained, it seems difficult to generalize to all children an improvement of social

Regarding children's engagement in the group, there was no significant increase in the number of responses when QT was active. Despite a strong interest in QT at the beginning of the experiment, as the sessions progressed, the patients were increasingly less sensitive to the robot's positive reinforcements. The experimenters often had to point out when QT had intervened ("Did you hear QT? He said he is proud of you!"). In addition, adult interventions seemed to have a greater impact on the children's behavior than the robot's behavior did. For example, when a child lost interest in the group, it was the adult's prompting that allowed the child to re-engage in the activity. Although some children sometimes called out to QT, the participants primarily solicited the adults and sought their attention. It is also important to note that the scoring of engagement (the number of responses to social interaction requests and the number of interaction initiations) was conducted during a single activity rather than the entire session, and this activity was particularly conducive to placing QT in the interlocutor position.

Based on the literature on social robots (Tisseron & Tordo, 2018), we also hypothesized that the presence of QT would allow for a decrease in negative behaviors and an increase in positive behaviors of the children within the group. We found a positive effect on maladaptive behaviors during SSG, but it was not specific to sessions when QT was active as there were no significant differences in children's behaviors as a function of QT's status. The improvement in the children's behaviors seemed to be related to the establishment of a therapeutic framework within the group and to the progressive adaptation of the activities to the patients' cognitive and language level (Reichow, Steiner & Wolkmar, 2012).

*R2C3 interface design improvement*

Beyond these observations, we believe that the score of initiations significantly increased in contrast to the responses because of the limited capacities of the interface used, which seemed to favour the children's initiations. Indeed, QT was able to answer the children's questions but had difficulty engaging them in interactions (very few questions were available, and there was no possibility to rebound on a child's initiation). During the last activity, the participants showed real pleasure in questioning QT and learning more about him; they asked him questions spontaneously, were happy when he shared his tastes and expressed pleasure in giving him the

pictogram corresponding to what they liked ("Do you like the fox, QT?", "Do you want some chocolate?"). However, the interactions were often limited to one response from QT without the possibility of rebounding on the response. The participants tended to respond more to the adults' prompts than to the robot's. Other aspects of the R2C3 interface could be improved when implementing it in an SSG. These limitations explain its moderate scoring of the DICTI (Grossard et al., 2023). Due to the group scenario, the interface did not allow the robot to initiate interactions with more than one participant at a time. Nevertheless, the therapists were able to rebound on single child-robot interactions and generalize them to the rest of the group. They did so by involving the other participants in the child-robot interaction and creating a group dynamic between all participants based on the robot's interaction. Similarly, R2C3 lacked the ability to adapt the robot's behaviors to the specific needs of each patient by proposing, for example, different levels of complexity in the robot's responses. Globally, exchanges with QT were very limited by the lack of customization of its interventions. QT's comments were predefined, and therapists could neither modify nor add to them. For example, when a participant asked QT a question, the adult had to almost systematically rephrase it as QT could answer only closed-ended questions.

The R2C3 robot's intonation/prosody also lacked modulation and expressiveness, accentuating the artificial impression of its answers (Park et al., 2017). Similarly, the range of emotions offered by the interface was quite limited. R2C3 did not have the option to share his emotional state but only to comment on others' emotional states ("You look sad", "You look angry"). Furthermore, he could not express his agreement or disagreement to create reciprocal social interactions (e.g., "Me too", "Me neither").

Finally, the time lag between the Wizard of Oz control and the behavior execution made the reactions less spontaneous or even unsuitable for some activities. The computation of adaptive algorithms should improve QT's turn taking (Skantze, 2021). Moreover, unlike other social robots such as SAR NAO (Wigelsworth et al. 2010), QT was limited in its movements (it could only move its arms), which restricted its use for certain physical activities.

## *Limitations*

This study presents obvious limitations due to its exploratory design. A control group was not included, and the number of participants and duration of the study were limited. In addition, there is currently no scale that can effectively measure social skills in their entirety (Wigelsworth et al., 2010). The ADOS-2 module was used to assess specific ASD domains, such as social skills, communication and maladaptive behaviors, based on the sessions' video recordings, but it may not be sensitive enough to detect changes in skills over time. Additionally, our study did not include a follow-up, and our evaluations focused on the children's behaviors within the group and not on the transfer of their skills to everyday life. The R2C3 interface displayed several limitations, primarily related to its design, which was not specifically intended for use in an SSG for autistic children. Because it was originally developed for the iReCheck project to rehabilitate writing skills in children with dysgraphia (Zou et al, 2021), certain features should be redesigned to be better suited for an SSG. The lack of customization/personalization of R2C3 appeared to be one of the main barriers in child-robot interactions during SSG. Personalizing the interface could enhance the user experience, increase the efficiency of the interaction, and ultimately facilitate the naturalness of the social exchange (Anzalone et al., 2012). We believe the interface could be improved to fit the needs for an SSG based on the overall promising results of the current study.

## *Conclusion*

We investigated the feasibility and usability of the R2C3 robotic interface and the impact of the SAR QT in an SSG for autistic children. Our observations revealed that it is feasible to include the R2C3 Wizard of Oz interface in combination with the SAR QT in an SSG. The robot's social reinforcement complemented the clinicians' effectiveness during the sessions. From a usability standpoint, the interface is suited for non-technological participants. Quantitatively, our results suggest that the use of QT in active mode leads to a significant increase in social interaction initiations but does not show a significant improvement in responses to social interaction requests and ADOS scores. Both the active and inactive conditions demonstrated a significant improvement in the participants' social skills after the ten group sessions. This study presents possibilities for future research on the benefit of SARs in SSG for autistic children pending some improvements of the R2C3 interface. Future research

should take into account the possibility of personalizing the interface, the latency between behaviors, and additional specific social behaviors.

# *Chapter 6: Can a home-based serious game for autistic children improve their social skills?*

**Abstract**

**Background:** Over the past decade, digital tools have been increasingly studied in Autism Spectrum Disorder (ASD) care. New alternative developmental approaches that incorporate play therapy are being suggested, including Serious Games (SG). e-GOLIAH is a digital gaming platform inspired by the principles of the Early Start Denver Model (ESDM) aiming to improve the social and communication skills of autistic children through games focusing on joint attention and imitation skills.

**Methods and Design:** 150 children aged 3 to 6 years old diagnosed with ASD and their parents will be recruited into this single blind, randomized controlled trial using a serious game, e-GOLIAH. Eligible participants will be randomized to the treatment group "GOLIAH", which will provide therapy as usual plus the digital game home-based intervention and the control group will receive therapy as usual for 12 months. The GOLIAH group will receive two interconnected tablets per household, one for the child and one for the parent. e-GOLIAH gaming platform design will be evaluated with the Design ICT Inventory (DICTI).

**Discussion:** This randomized controlled trial will determine the effectiveness of the SG e-GOLIAH as a complementary tool to ASD treatment. This trial will also determine the feasibility of a parent delivered home-based intervention aiming to improve the participants' social interactions by practicing imitation and joint attention skills. Additionally, we will evaluate the cost-utility 12 months after the e-GOLIAH was implemented at home, versus treatment as usual alone. The SG design quality was assessed using the DICTI, resulting in a moderate score of 15 out of 26. Noteworthy features included its simplicity to use, clarity of instructions and difficulty management.

**Trial Registration:** This research is registered on the site http://clinicaltrials.gov/ under the number registration No. NCT05271955.

**Keywords:** Autism Spectrum Disorder, serious games, home based intervention, parent delivered intervention, social skills, imitation, joint attention

## *Introduction*

Autism Spectrum Disorder (ASD) presents deficits in social skills and communication prerequisites such as imitation and joint attention (APA, 2013). These acquisitions are necessary for the development of more complex social skills and can have a significant impact on the academic and socio-professional integration of autistic individuals (Tomasello, 2005). Enabling autistic children to develop their social skills from an early age is therefore a major challenge for their developmental trajectory. Several reviews recommend specific work to develop the field of social interactions (Gosling et al., 2022). Social skills training aims to improve communication, the expression of feelings and interactions, by transmitting interpersonal skills to patients and promoting their generalization and maintenance (Baghdadli, 2011).

In recent years, there has been a significant rise in the development and utilization of Information and Communication Technologies (ICTs), notably serious games (SG) in the care of ASD (Grossard et al., 2017; Kokol et al., 2020; Tsikinas & Xinogalos, 2019). SGs are described as a combination of education and entertainment (Grossard et al., 2018), utilizing gaming elements like storylines, long-term goals, and rewards, while offering enjoyable educational experiences (Whyte, Smyth & Scherf, 2014). These games are accessible through various platforms, including tablets, smartphones, and computers, making them widely available. The potential of SGs lies in their versatility, providing training opportunities across a wide range of skills in different settings (Grossard et al., 2017). Most SGs for ASD care focus on social skills development, such as interaction, collaboration, and adaptation to specific contexts; most specifically they target facial emotion recognition or production (Grossard et al., 2017). Studies have found that SG are effective for the development of social skills and in providing supports that create immersive social situations, in comparison to therapy as usual (Grossard et al., 2018). In a review, Grossard et al. (2017) referred to 31 serious games that aim to teach social interactions. However, SGs face some limitations in their research and application. First, the current available SGs are mostly developed for high-functioning autistic individuals (Grossard et al., 2017). Some literature also points it out to be the case in random controlled trials with the exclusion of severe autistic children (comorbid intellectual disability (ID) or challenging behaviors), which are not representative of the clinical population in clinical practice (Salomone et al., 2016; Hyman et al., 2020). Secondly, SGs clinical validation does not often meet the evidence-based medicine standards (Grossard et al., 2017), limiting the generalizability and

lasting effects of the results. For the exception of some controlled studies (Klingberg et al., 2002; Temple et al., 2013; Francheschini et al., 2013) or random control trials including large sample sizes (Klingberg et al., 2005; Golan & Baron-Cohen, 2006; de Vries et al., 2014). Additionally, there is a lack of game design description and rationale behind its development. Finally, the clinical validation and playability/game design are not compatible (Grossard et al., 2017).

The design of serious games (SGs) is of significant importance when applied to autism care. The unique characteristics of autistic individuals necessitate a design that fit the needs and heterogeneous profiles of autistic individuals (Allen et al., 2016). A recent meta-review evaluating the evolution of ICTs design and research methodology implications over the last decades, revealed that SGs design strengths include games related to social context, multiple feedbacks, multiplayer options and possibility to personalize the digital platform (Grossard et al., submitted). Furthermore, autistic individuals often have diverse sensory preferences and sensitivities (Quill, 1997). Therefore, game developers must consider factors such as visual and auditory stimuli and overall sensory experience to ensure that the game is comfortable and engaging for autistic users. Finally, affordability must also be taken into consideration, since apps can sometimes be expensive. Of note, only EndeavorRx™, an Akili's video game therapy for ADHD (Canady, 2020; Kollins et al., 2020) has been approved for therapeutic use by the U.S. Food and Drug Administration (FDA) (Allen et al., 2016), making it the first SG to be reimbursed.

This article aims to continue the exploratory work of Jouen et al. (2017) with GOLIAH SG, by presenting the protocol of a randomized controlled trial which will evaluate the efficacy of the SG, determine the feasibility of a parent delivered home-based intervention as well as evaluate the cost utility of 12 months after e-GOLIAH + treatment as usual (TAU) versus TAU alone. The previous work included 14 autistic participants and 10 controls, ages 5 to 7. Results found that children and parents engaged in 40% of the sessions. The 11 games were successfully utilized, leading to enhanced task performance timing and improved imitation scores within the majority of imitation games for participants trained with GOLIAH. Notably, the GOLIAH intervention had no impact on Parental Stress Index scores. At the conclusion of the study, both groups displayed significant improvements in Autism Diagnostic Observation Schedule (ADOS-2) scores, Vineland socialization score, Parental Stress Index total score, and Child Behavior Checklist internalizing, externalizing, and total problems (Jouen et al., 2017). An encouraging

study to investigate more GOLIAH was given by Billeci et al. (2017) as they found a correlation between the improvement in performing joint attention tasks after training with GOLIAH and a "normalization" of brain activity and connectivity profiles recorded in quantified EEG. Furthermore, this article aims to evaluate and provide feedback on the design quality of the SG e-GOLIAH through the Design ICT Inventory (DICTI, Grossard et al., 2023).

*e-GOLIAH platform description*

As part of the European research project FP7, the team of the MICHELANGELO consortium associated with the universities of Pisa, Southampton, Paris 6 and the team of the child and adolescent psychiatry department of the Pitié-Salpêtrière Hospital, developed GOLIAH, a digital game platform for autistic children. e-GOLIAH, a more user-friendly version that is accessible online, has been developed by MindMaze in collaboration with the Center de Ressources Autisme Ile de France and the CHU Pitié-Salpêtrière Hospital, via the Autism and New Technologies call for projects launched by FIRAH in 2016. This version is distributed on the *curapy.com* platform, which allows for simplified accessibility and large-scale distribution.

e-GOLIAH is inspired by the principles of the ESDM (Early Start Denver Model, Dawson et al., 2010). It is designed for early, intensive and home-use and allows regular therapeutic assessment (Bono et al., 2016). The SG aims at improving the social skills and communication of autistic children through games involving joint attention and imitation. These two skills are the keys to early social interaction and communication (Jouen et al., 2017; Tomasello, 2005). The serious game offer a simple, playful and colorful graphic design, adapted to autistic children. This favors the accompaniment of the child outside the clinical environment, while maintaining the link with health professionals. Indeed, the therapist, via the platform, identifies the child's difficulties and follows their evolution and compliance with the sessions. It is an innovative method of intervention in the natural environment, centered on the child, practiced at home and involving the parents.

In addition to the classic role of guidance, some e-GOLIAH games are designed to practice joint actions directly with the helper in a fun and interactive way. Indeed, unlike most SGs where the child plays alone or isolated, e-GOLIAH promotes interaction and cooperation by coupling two connected tablets (the child’s and the caregiver’s). Thus, the games offered by e-GOLIAH constrain the interaction between partners since it is limited to two players. This forced

collaboration encourages the child to perceive the adult as a communication partner (Cohen et al., 2017).

*Descriptions of the games*

e-GOLIAH is composed of ten mini games: six games practicing imitation skills (Figure 1) and four games practicing joint attention skills (Figure 2) where the child and the parent can play together with the use of two connected tablets. Please refer to Bono et al. (2016) for the games' description.

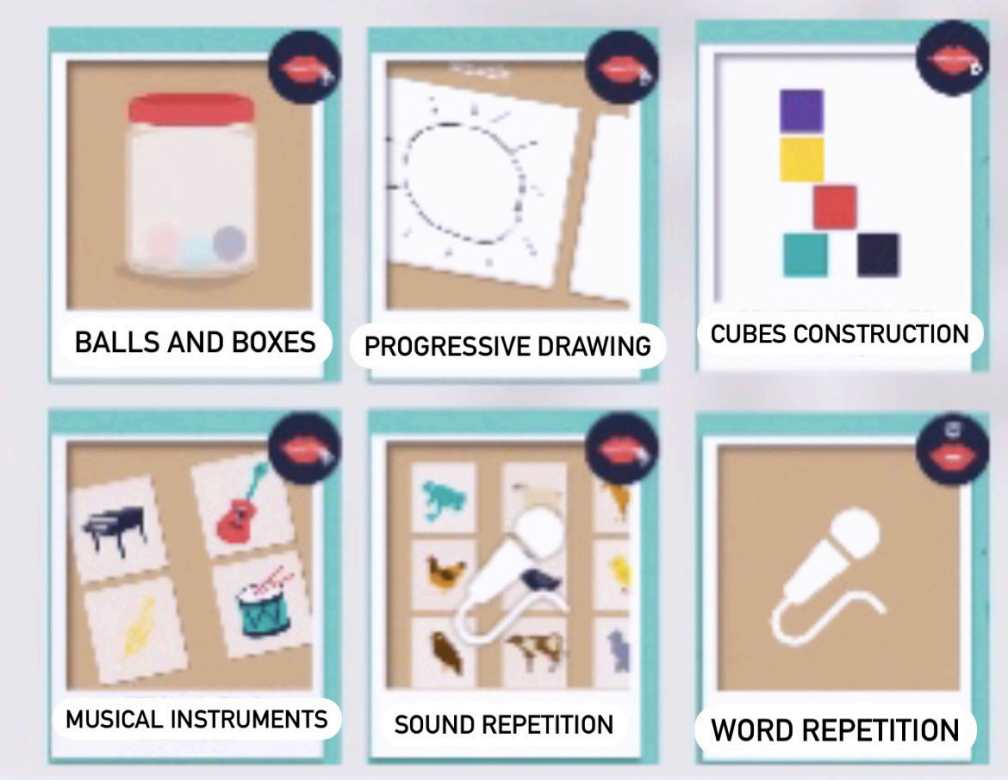



**Figure 1. Imitation games**

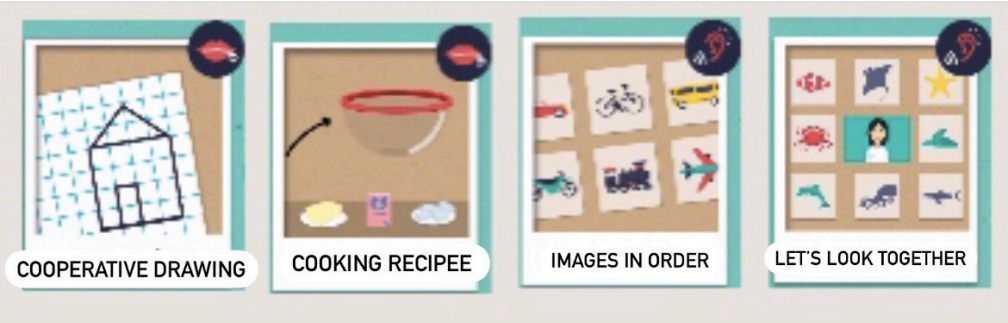



**Figure 2. Joint attention games:**

*Objectives of the study*

**Primary objective**

- Evaluate the cost-utility at 12 months of the management of children diagnosed with ASD using the e-GOLIAH game in the home, compared with usual care.

- Measurement of the incremental cost-utility ratio (ICER) at 12 months for the management of patients with ASD using the therapeutic game e-GOLIAH at home plus usual care, compared to the measure of the 12-month incremental cost-utility ratio (ICER) of managing patients with ASD using the e-GOLIAH therapeutic game in the home, compared to usual care alone, will be derived from the EQ-5D-5L/EQ-5D-Y scale.

**Secondary objectives**

1- Medicoeconomic

- Evaluate the cost-effectiveness of managing patients with ASD using e-GOLIAH vs. to the usual management at 12 months of follow-upExplore the annual ASD-related out-of-pocket expenses of the cost of illness of the two groups studied.

- Evaluate the consequences of generalizing the management of children diagnosed with ASD using with e-GOLIAH, compared to usual care, from the point of view of the Health Insurance over a period of over a period of 3 years.

2- Clinical

- Evaluate at 6 months and 12 months the impact of the management of children diagnosed with

ASD using the e-GOLIAH game used at home, compared to a usual care, on:

- Child and parent quality of life (EQ-5D-5L/EQ-5D-Y by proxy)
- Adaptive symptoms (Vineland-II, Sparro, Balla & Cicchetti, 2005)
- Autistic symptoms (CARS, Reichler & Schopler, 1971)
- Social interaction progress (Social Responsiveness Scale, John N. Constantino, 2012)
- Parental stress (Parental Stress Index, Abidin, R. R. (1983). French adaptation, Bigras et LaFrenière, 1996)

3- Game Acceptability

- Assess compliance by children and their caregivers at home.

## *Methods & Design*

**Participants**

This study will include 150 young children with ASD aged 4 to 6 years old and at least one caregiver who will be recruited across 12 centers in France.

The eligibility criteria will include:

(a) Autistic children more or less mild cognitive deficit by the Autism Diagnostic Interview (ADI-R) (Rutter, Le Couteur & Lord, 2003) or the Autism Diagnostic Observational Scale (ADOS-2) (Lord et al., 2012),

(b) Aged 3 to 6 years;

(c) Family ready to get involved in the constraint of using the SG 5 times / week at home

(d) Signature of the consent by the 2 holders of parental authority or the only holder of parental authority present

(e) Affiliation to a social security scheme (except AME)

***Exclusion criteria***

(a) Children with behavioral problems;

(b) Unstabilized comorbid organic pathology; moderate and severe cognitive deficit (Intellectual Quotient less than 55);

(c) Multi or poly handicap;

(d) Taking medication that may cause visual or cognitive impairment (APS, neuroleptics, etc.) or may interfere with study assessments;

(e) Degenerative diseases or any other disease that could interfere with the evaluations planned during this study (known epilepsy and/or history of seizures, etc.);

(f) Photosensitive people in order to avoid situations likely to induce epileptic seizures in them.

*Sites recruitment*

Recruitment will be national via the network of Autism Resource Centers involved in the study. Table 1. describes the planned recruitment in each center.

**Table 1. Expected recruitment across the centers**

| **City** | **X of patients expected per month** | **Total recruitment 9x patients)** |
|---|---|---|
| Strasbourg | 0.69 | 13 |
| Montpellier | 0.69 | 13 |
| Nice | 0.69 | 13 |
| Versailles | 0.69 | 13 |
| Amiens | 0.69 | 13 |
| APHP-SU, Paris | 0.69 | 13 |
| APHP Necker Paris | 0.69 | 13 |
| Nancy | 0.69 | 13 |
| Toulouse | 0.69 | 13 |
| Tours | 0.69 | 13 |
| Poitiers | 0.69 | 13 |
| Paris 14th | 0.69 | 13 |

***Study design & Randomization***

Randomized, open-label clinical trial comparing children receiving standard treatment plus intensive use of e-GOLIAH (experimental group) with children receiving standard treatment only (control group) Randomization will be centralized by an online randomization module integrated into the e-CRF (Cleanweb).

**Table 2. Inclusion Visit and Consent**

| **Persons whose consent is sought** | **Who informs and obtains consent** | **When the person is informed** | **At what point is the person's consent obtained** |
|---|---|---|---|
| The 2 holders of parental authority or the sole holder of parental authority present | The collaborating physicians declared and trained for the research (child psychiatry or psychiatrist) screening visit | Screening visit | Inclusion visit; after a reflection period of at least 1 week |

Following the signature of the consent form by the two parental authority holders or by the only parental authority holder present, the inclusion visit will consist of explaining and training the parents in the use of e-GOLIAH, in the connection to the CURAPY.COM platform after having created their account and that of their child. The inclusion visit will also collect the variables at T=0, namely:

- EQ-5D-5L and EQ-5D-Y proxy scales (children)
- EQ-5D-5L scale (parents)
- Vineland-II scale (if not done at the screening visit)
- CARS scale
- SRS scale
- Parenting Stress Index scale

- Medicoeconomic data

During the inclusion visit, socio-demographic information and details of usual treatment will be collected (consultation, number, frequency and type of rehabilitation, school inclusion, School Life Assistant (number of hours), home educator (number of hours), other care.

**Table 3. Study procedure and evaluation criteria summary**

| | | | Selection | Inclusion | M6 | M12 |
|---|---|---|---|---|---|---|
| Information notice | | | **X** | **X** | - | - |
| Autism Spectrum Disorder (ASD) Diagnostic: ADI-R or ADOS and Vineland-II | | | **X** | - | - | - |
| Informed consent | | | - | **X** | - | - |
| Inclusion and non-inclusion criteria verification (by a doctor) | | | - | **X** | - | - |
| Randomization | | | - | **X** | - | - |
| E-Goliah game | | | - | Game training | - | - |
| EQ-5D-5L and EQ-5D-Y by proxy (children) | | | - | **X** | **X** | **X** |
| EQ-5D-5L (parents) | | | - | **X** | **X** | **X** |
| CARS | | | - | **X** | **X** | **X** |
| Vineland II (in case not done during the selection visit) | | | - | **X** | - | **X** |
| SRS | | | - | **X** | - | |
| SPI | | | - | **X** | **X** | **X** |
| Collection of personal data (NIR, DN and sex: child and parents) (separate file) | | | - | **X** | - | - |
| Skype or Phone check-in | Group e-GOLIAH : Every 15 days. Game Update | Control Group Every 30 days. General point | - | - | M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12 | |
| | Data on consumption of non-health care for the 2 groups | | - | M1 → M12 | | |

***Clinical Outcome measures***

The following clinical variables will be assessed in the experimental and control groups at entry and at 6 months:

- Adaptive symptoms will be measured with the Vineland-II (Sparro, Balla & Cicchetti, 2005): it is a socio-adaptive behavior scale with four dimensions, three of which will be considered: socialization, communication, and daily living skills; and a composite adaptive behavior score that combines these three dimensions). This scale will be completed during the interviews with the parent or the referring educator.

- Autistic symptoms will be measure with the CARS Child Autism Rating Scale (CARS, Reichler & Schopler, 1971) consists in 15 items will be evaluated with a 4-level Likert scale.

- Social interactions will be measured with the Social Responsiveness Scale (SRS, John N. Constantino, 2012). This is a questionnaire about the child that will be completed by the parents or the referring educator during the interviews.

- Parental stress levels will be measure with the Index Stress Parental (Abidin, R. R. (1983). French adaptation, Bigras et LaFrenière, 1996), which consists in a standardized questionnaire with two dimensions regarding the stress associated to the child and to the parents.

***Medico-economic outcomes***

Primary endpoint: cost-utility, based on 3 elements:

1. Collection of consumption (excluding social security) in the case report form (CRF)
2. Personal data from the Health Insurance (SNDS)
3. EQ5D questionnaire

The child's acceptability to the game e-GOLIAH at home will be evaluated qualitatively during the interviews with the parents or the referent educator and quantitatively from the times of use counted by the tablet.

***Description of the planned statistical methods including the timing of planned interim analyses***

A patient-tracking chart will highlight the number of eligible patients and the number of patients actually included in total and in each of the two arms. For each group and at each evaluation date, the qualitative variables will be described by their number, percentage and missing data per response modality and the quantitative variables by their number, mean, standard deviation. Quantitative variables with asymmetric behavior will be presented with their median and interquartile range (25th percentile - 75th percentile).

In accordance with the recommendations, the calculation of the Number of Subjects Needed (NSN)necessary subjects (NSN) was carried out based on assumptions on the primary endpoint. We used the formula proposed by Glick, where the numbers and standard deviations of costs and results are equal in the 2 groups (Glick, 2011).

Thus, with a power of 80%, we formulate the following hypotheses:

• Maximum acceptability threshold: €60,000 (Court of AuditorsCour des comptes 2017, HAS 2014)

• Cost difference: 1000€ AND ±1000€

• Utility gap (QALY gain): 0.04 AND SD ±0.03 (Van Steensel, 2014)

• Correlation coefficient between cost and utility: -1.

That is 63 subjects per group:

We will take into account 20% of those lost sight ofdropouts by considering the difficulties that parents (or children) may encounter playing with e-GOLIAH for the duration of the intervention. That is 75 patients per arm.

In total, the Number of Subjects Needed (NSN) is 150; the number of participating centers is 12 and each center will include at least 13 patients. Patients will be randomized individually with stratification by center. For the sake of safety, we are opening 12 centers to maximize the chances of recruitment.

***Medico-economic analysis***

The medico-economic analysis will be conducted according to international recommendations (Husereau 2013) and the French National Authority for Health (HAS 2011). The cost-utility and cost-effectiveness analyses will be performed at 12 months.

Cost-utility analysis:

Considering that quality of life is related to the health status of these ASD patients (Kuhlthau 2010 García-Villamisa, 2010), a cost-utility analysis is preferred (HAS 2011).

a) Type of analysis:

The analysis will consist of a comparison of the two patient management strategies:

- Strategy 1 = control group: "Usual treatment" and

- Strategy 2 = intervention group: "Usual treatment + the e-GOLIAH game".

The perspective will be collective (households, health care providers, health system and community) with a time horizon of 12 months from inclusion (without discounting of costs and consequences).

(b) Outcome criterion:

The outcome criterion will be lifetime weighted by preference scores (QALY). The preference scores will be derived from the EQ-5D-5L validated in France.

c) Analysis population:

The population directly concerned is the set of children affected by ASD, followed in one of the centers participating in the clinical investigation and who will meet the selection criteria cited in the paragraph "Description of the population".

d) Costing method:

Direct medical and non-medical costs related to the management of patients or their complications, to the implementation and operation of the innovation, by type of consumption and by patient in each group will be considered. Production and productivity losses will be documented even if the patients are not of working age. Nevertheless, we believe that it would be useful to systematically collect them in the framework of this PRME, as such a study has never

been done in France. We will include them in a complementary analysis. The intangible costs will not be measured as such since they will be captured indirectly by the utility measure based on QALYs.

## *Discussion*

This new e-GOLIAH clinical trial will be randomized and controlled. The experimental group will have access to e-GOLIAH at home in addition to their usual care. At the first meeting with the parents of both groups, we will administer an initial questionnaire to establish a profile of the family dynamics around playing. We will also evaluate the child's social and language skills using the Child Development Inventory (CDI). This information will allow us to report on the evolution of the children throughout the study. It will also be compared between the two groups in order to evaluate the impact of the use of e-GOLIAH in regards to imitation and joint attention skills, as well as the impact on the parents' stress levels.

Based on a previous pilot study of the GOLIAH serious game (Jouen et al., 2017), results appear to be mixed and require careful interpretations. First, 40% of the planned sessions were completed, indicating that participants were able to engage with the platform. This also indicates that the serious game usable and acceptable to autistic children and parents. Secondly, participants who trained with GOLIAH showed improvements in their ability to perform tasks related to the targeted skills, joint attention and imitation in most of the associated games. The results suggest that the platform has the potential to effectively enhance these precursors of social skills, which are important to develop more complex social skills. However, Both the group using GOLIAH and the control group showed significant improvements in various aspects, including Autism Diagnostic Observation Schedule scores, Vineland socialization score, Parental Stress Index total score, and Child Behavior Checklist scores. This suggests that both groups benefited from some form of intervention, but it's unclear if GOLIAH was more effective in this regard. Perhaps the most significant finding is that there was no significant difference between the GOLIAH group and the control group in terms of addressing core symptoms of autism. This suggests that while GOLIAH may improve specific skills, it may not be more effective than the standard treatment used in the control group. The study concludes by emphasizing the need for further research, particularly in a larger randomized controlled trial with younger participants. While initial results are encouraging, more rigorous testing is needed

to establish a significant efficacy of GOLIAH in the training of social skills, notably imitation and joint attention.

**Assessing the design of the serious game e-GOLIAH**

**Table 4: Design ICT Inventory" (Grossard et al., 2023)**

| Item | Rating |
|---|---|
| 1) possible customization by the user | 0 |
| 2) feedback | 1 |
| 3) rewards | 1 |
| 4) contextualized learning | 0 |
| 5) enhance motivation | 1 |
| 6) manage difficulty or complexity | 2 |
| 7) increasing accessibility: simplicity of use and autonomy | 2 |
| 8) clarity of the instructions and content | 2 |
| 9) attention capacity | 0 |
| 10) clear steps or goals for short and long term | 2 |
| 11) easy to process and modify graphics and audio | 0 |
| 12) human interaction | 2 |
| 13) trustworthy | 2 |

The SG e-GOLIAH's design quality was assessed using the DICTI (Grossard et al., 2023), resulting in a total score of 15 out of 26 (refer to Table 4), indicating a moderate rating. Noteworthy features include its user-friendliness even for non-technical users, and the ability to adjust difficulty levels from 1 to 3, allowing parents to gradually tailor the game complexity to their child. Moreover, clear visual instructions guide parents through each game, and specific

sound feedback indicates correct or incorrect answers. After each successful game, an animated avatar provides non-verbal positive feedback, potentially enhancing the child's motivation and engagement during gaming sessions. Conversely, in line with the literature examining SG, the platform lacks personalization options (Charlop-Christy et al., 2000), verbal positive feedback (Spriggs et al., 2015), and task reminders, which could also serve as external stimuli to maintain the child's engagement and promote learning.

## *Conclusion*

This protocol presents the upcoming clinical evaluation of the serious game e-GOLIAH. The randomized trial will also examine the viability of a home-based digital intervention, led by parents, with the objective of enhancing participants' social interactions and decreasing parental stress through the practice of imitation and joint attention skills. Furthermore, an assessment of cost-effectiveness will be conducted twelve months after the implementation of e-GOLIAH at home, in comparison to the standard treatment protocol. Finally, the design quality assessment of the SG shows promise, with a moderate score of 15 out of 26. This highlights its positive features, including user-friendliness, clear instructions, and adaptability in difficulty levels. Additionally, it's worth noting that incorporating features such as personalization, verbal feedback, and task reminders, as suggested in the literature, could further enhance its potential promoting learning.

# *Chapter 7: General Discussion*

The research project of this thesis was to take a multidisciplinary approach including clinical and engineering perspectives to the development and implementation of ICTs in the care of individuals with NDD, and most specifically autistic children. The exponential growth of digital tools providing innovative approaches to ASD care has been the subject of significant research over the last decades (Grynszpan et al., 2014; Hollis et al., 2017; Miguel Cruz et al., 2017; Khan et al., 2019; Grossard et al., 2018). However, there is currently no standard framework to evaluate ICTs, and this increase has created an urgent need to investigate the design quality of the relevant technologies and their clinical impact on outcomes.

The development of the Design ICT Inventory (Grossard et al., 2023) aimed to fill in this gap by providing a framework to ICT developers and researchers to take into consideration specific features related to the heterogeneous profiles and needs of individuals with NDD. For the purpose of this first project, through a Delphi study, and with the support of twelve ICT experts, we were able to develop the first framework to assess ICTs' design. We then evaluated the evolution ICT design and study methodology of the existing literature of clinical trials implementing digital tools in the care of individuals with NDD. We conducted a meta-review of ICTs applied to individuals with NDD, where we applied the DICTI (Grossard et al., 2023) for ICT design, and the methodology Connolly scale (Connolly et al., 2012) to several randomly assigned study groups regarding the most frequent ICT (SG, VM, robots and AAC). We also summarized the most cited studies and articles from journals with the best impact factor. Our results revealed that AAC, VM and robots' design quality did not improve overtime, whereas SG' quality score did. In parallel, we were interested in assessing the methodology design quality of these clinical trials with the use of the Connolly scale (Connolly et al., 2012).

Our results pointed out that the overall research methodology quality improved over the years for VM, AAC and specially robots, but not for SG, who in contrast appear to have the best ICT design quality. We observed that most clinical trials have poor methodologies due to the nature of the study design. While Randomized Controlled Trials (RCTs) are considered the gold standard for research quality to assess the effectiveness of interventions, the field of ICTs includes alternative experimental designs prior to conducting an efficacy trial. Initial phases, including feasibility and usability trials, are essential to evaluate the implementation of ICTs NDD care. These studies do not require high quality study design and often take the form of case

studies (Liu et al., 2017) or group series without control group (Bargagna et al., 2018). The improvement of research design could be explained with the time frame evolution of the different experimental phases of such research. However, despite of the methodology improvement over the years, we observed that most studies have a small number of participants (Parsons et al., 2019), a challenge that persists.

From the engineering design perspective, we found an agreement between the available literature and DICTI results. First, the number of design features has increased over the last decades leading to more sophisticated and more technologies adapted to the needs of individuals with NDD. There is also a consensus to the need for ICT personalization, allowing the users to engage effectively with the digital tools, i.e.: personalization of visual design (characters, backgrounds, sounds or colors), content, and messages, have proved to have an impact on users' engagement and satisfaction (Allen et al., 2016). However, most ICTs do not include personalization options, which could be due to the complexity of the algorithms permitting such adaptations. Additionally, positive feedback and rewards are now well established as they have been linked to promoting learning in children with NDD (Horn et al., 2008; Litras et al., 2010; Spriggs et al., 2015). However, these features mostly appear in SGs. This field has likely benefited from the enormous effort in research design coming from the gaming industry for children and adolescents developing typically. SG design improvement stands out, potentially due to its success in the economic market, which has led to more funding and easier experimentation. This virtuous circle in serious games contrasts with other ICTs that lack financial support and face more challenges in the experimentation and implementation of the digital devices. In the case of individuals with NDD, positive feedback is necessary to keep the user in track of their work while also maintaining their attention (Whyte et al., 2015). Furthermore, contextualized learning, accessibility, clarity of instruction and goals have also been linked to a better usability of the digital tool (Grossard et al., 2017).

The overall perception of the ICT is often documented in ICT clinical trials (Allen et al., 2016), as they provide knowledge of the disorders but also the needs of the individuals and the institutions they work for (Guard et al., 2019). Most studies include a social validity section, which presents the perception of the ICT addressed by NDD users, caregivers or teachers.

Contemporary issues regarding privacy and security have highlighted the importance of ethics when developing and implementing ICT care devices with NDD people

(Schultz, 2005). Ensuring confidentiality and security of personal data collected during ICT interventions, while also obtaining users' consent, is of outmost importance. Additionally, as we have seen with the development of any new technology, affordability remains a challenge for individuals with low socioeconomic situations. Addressing these inequalities and providing affordable ICTs can prevent disparities in therapeutic and educations opportunities (Schultz, 2005). Third, in alignment with the development of artificial intelligence language processing tools (i.e.: ChatGPT), addressing emergent issues of misinformation and misbehaviors are critical when developing autonomous algorithms, specially applied to social robots (Kaloudi & Li, 2021). Our second exploratory project involved the implementation of a social robot in a social skills group setting for autistic children (Bettencourt et al., 2023, submitted). A remarkable amount of research has shown that social robots can have positive therapeutic outcomes for autistic children by promoting the development of social skills (Saleh, Hanapiah & Hashim, 2021; Scassellati et al., 2018; Sartorato, Przybylowski & Sarko, 2017). Indeed, autistic children face deficits in the development of social skills that prevent them from creating reciprocal and adapted relationships, and affect their overall wellbeing.

Despite the growth of social robots research in ASD individual care, the implementation of a robot within a group setting remains underdeveloped. We therefore became interested in investigating the feasibility and usability of the Wizard-of-Oz Rehabilitation Robotic Companion for Children and Caregivers (R2C3) interface developed by our colleagues, aiming to improve handwriting difficulties for children with dysgraphia (Zou et al., 2021). Due to the already existing social behaviors included in the robotic interface, we selected specific behaviors, which we thought could complement the groups' activities and dynamics. Most particularly, we chose the positive reinforcement, encouragements, emotions' recognition and expression categories, and finally a conversational category to collect participants' feedback. We created the social skills group curriculum based on Ozonoff and Konstantareas' recommendations (Baghdadli et al., 2013), including structured and predictable sessions, visual supports, and activities facilitating emotion recognition, communication and problem solving scenarios. Each activity was centered on crucial social skills including imitation, joint attention and turn taking, which are necessary for the development of more complex social skills (Tomasello, 2005).

Results revealed that the robot did not prevent the effectiveness of the social skills group. All children presented more social openings towards the other children and researchers in

the group as the sessions progressed. Additionally, we found no differences between the active and inactive robotic interfaces. However, we observed that the use of the robot resulted in increased engagement and interaction initiations. Our results also revealed the impact of the novelty effect on children's engagement prior and during the intervention (Leite et al., 2009; Sung, Christensen & Grinter, 2009). Nonetheless, we observed several limitations in the interface, primarily related to its design. Consistently with the literature, the lack of personalization appeared to be the main barrier in the social interactions within the group. Additionally, the robot was only able to answer open-ended questions, limiting the spontaneity and complexity of the social exchanges. Generally, it's believed that a robot's behavior significantly impacts a user's engagement, task performance, and collaboration in therapeutic and educational settings (Oertel et al., 2020). In a recent study using multimodal dataset in human-robot interactions (HRI), results revealed that certain behavioral aspects related to task and/or social engagement have the ability to predict learning outcomes, and these aspects are occasionally separate from task performance (Nasir et al., 2022). This research has created new perspectives in robot's design regarding machine-learning engagement detection models.

Although the feasibility nature of the study did not allow us to draw conclusions on the efficacy of the social robot on the participants' social skills, usability and feasibility results, in addition to the effect on the participants' engagement, are promising. To maintain a constant interest in the robot and create more complex and fluid interactions, the design of the interface, notably the possibility to customize the interface is primordial (Anzalone et al., 2012). Generally, it's believed that a robot's behavior significantly impacts a user's engagement, task performance, and collaboration in therapeutic and educational settings (Oertel et al., 2020). In a recent study using multimodal dataset in human-robot interactions (HRI), results revealed that certain behavioral aspects related to task and/or social engagement have the ability to predict learning outcomes, and these aspects are occasionally separate from task performance (Nasir et al., 2022). This research has created new perspectives in robot's design regarding machine-learning engagement detection models. Future work should take into consideration DICTI results and the observations of this study, but also include clinicians specialized in ASD to develop a robotic interface adapted to the needs of a social skills group dynamic. Finally, our upcoming work also includes the evaluation of e-GOLIAH SG, aiming to improve children's imitation and joint attention, and decrease parental stress while improving the parent-child relationship and

treatment financial burden. Based on previous results (Jouen et al., 2017), the implementation of the SG platform is promising. Alongside the challenges posed by the COVID pandemics, the e-GOLIAH project has encountered administrative obstacles that have impeded its initiation. These challenges include the need to secure various authorizations and establish agreements between project partners. As a result, the study has not yet commenced due to these administrative complexities.

# *Conclusion*

This thesis demonstrates the potential of ICTs in NDD care. Additionally, it emphasizes the complexity of design choices and research methodology implications when developing and evaluating therapeutic digital devices for neuro-atypical populations.

The absence of standard evaluation framework for ICTs motivated the creation of the Design ICT Inventory (DICTI), a tool that aids ICT developers in considering the heterogeneous profiles and needs of NDD individuals. Our meta-review assessing the evolution of ICT design and research methodology over the last decades revealed the lack of high quality studies, despite of the promising results often presented. However, ICTs are not detrimental to therapeutic rehabilitation and learning, but due to most studies design, it is not possible yet to make generalizable conclusions. ICT designs appear to have improved over time, including more features within the platforms. In contrast, research methods limitations persist due to the nature of the research designs and recruitment challenges. Personalization, positive feedback, contextualized learning and accessibility, emerged as the most important features in ICT development.

The experimental project focused on the implementation of a social robot in social skills group for autistic children, illustrating the potential for engagement and interaction initiation, while also highlighting the robotic platforms' design limitations. Consistently with the literature examining ICTs in ASD interventions, we point out to the importance of personalizing ICT devices for optimal engagement and social interactions with autistic children. Finally, we aim to continue exploring the impact of ICTs in ASD care with the evaluation of the serious game e-GOLIAH. This will be done through a high quality randomized controlled trial to maximize the accessibility of digital interventions that can be implemented through an online platform (curapy.com) at the homes of autistic children.

# *Bibliography*


Albo-Canals, J., Martelo, A. B., Relkin, E., Hannon, D., Heerink, M., Heinemann, M., ... & Bers, M. U. (2018). A pilot study of the KIBO robot in children with severe ASD. *International Journal of Social Robotics*, *10,* 371-383.

Ali, N., Rigney, G., Weiss, S. K., Brown, C. A., Constantin, E., Godbout, R., … Corkum, P. V. (2018). Optimizing an eHealth insomnia intervention for children with neurodevelopmental disorders: A Delphi study. *Sleep Health, 4*(2), 224–234 https://doi.org/10.1016/j.sleh.2017.12.008

Allen, A. A., Jeans, C., Ball, L. J., & Guarino, A. J. (2015). Caregivers' perception of the iPad's utility for Augmentative and Alternative Communication (AAC): a conflict between illusion and reality. *World, 2*(1).

Allen, M. L., Hartley, C., & Cain, K. (2016). iPads and the use of "apps" by children with autism spectrum disorder: do they promote learning? *Frontiers in Psychology*, *7,* 1305. https://doi.org/10.3389/fpsyg.2016.01305

Alyssa Guard, M. S., & Michelle Konz, M. S. (2019). The development of an iPad application for the pain assessment of individuals with developmental disabilities and complex communication needs. *Assistive Technology.*

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders DSM-5* (5e éd.).https://doi.org/10.1176/appi.books.9780890425596

Andanson, J., Pourre, F., Maffre, T., & Raynaud, J.-P. (2011). Les groups d'entraînement aux habiletés sociales pour enfants et adolescents avec syndrome d'Asperger : Revue de la littérature. *Archives de Pédiatrie*, *18*(5), 589-596.https://doi.org/10.1016/j.arcped.2011.02.019

Anzalone, S. M., Boucenna, S., Ivaldi, S., & Chetouani, M. (2015). Evaluating the engagement with social robots. *International Journal of Social Robotics*, *7,* 465-478.

Anzalone, S. M., Yoshikawa, Y., Ishiguro, H., Menegatti, E., Pagello, E., & Sorbello, R. (2012). Towards partners profiling in human robot interaction contexts. *In Simulation, Modeling, and Programming for Autonomous Robots: Third International Conference, SIMPAR 2012, Tsukuba, Japan, November 5-8, 2012. Proceedings 3 (pp. 4-15)*. Springer Berlin Heidelberg.

Baghdadli, A., & Brisot-Dubois, J. (2011). *Entrainement Aux Habiletés Sociales Appliqué a L'autisme.* Elsevier Health Sciences France.

Bale, T. L., Baram, T. Z., Brown, A. S., Goldstein, J. M., Insel, T. R., McCarthy, M. M., ... & Nestler, E. J. (2010). Early Life Programming and Neurodevelopmental Disorders. *Biological psychiatry*, *68*(4), 314.

Bargagna, S., Castro, E., Cecchi, F., Cioni, G., Dario, P., Dell'Omo, M., ... & Sgandurra, G. (2019). Educational robotics in down syndrome: a feasibility study. *Technology, knowledge and learning, 24*, 315-323.

Baron-Cohen, S. (1997). Mindblindness: An essay on autism and theory of mind. *MIT press.*

Bartneck, C., Kanda, T., Ishiguro, H., & Hagita, N. (2009, September). My robotic doppelgänger-A critical look at the uncanny valley. *In RO-MAN 2009-The 18th IEEE international symposium on robot and human interactive communication(pp. 269-276).* IEEE.

Bauminger, N., Goren-Bar, D., Gal, E., Weiss, P. L., Yifat, R., Kupersmitt, J., ... & Zancanaro, M. (2007, October). Enhancing social communication in high-functioning children with autism through a co-located interface. *In 2007 IEEE 9th Workshop on Multimedia Signal Processing (pp. 18-21)*. IEEE.

Bellini, S. (2008). *Building social relationships: A systematic approach to teaching social interaction skills to children and adolescents with autism spectrum disorders and other social difficulties.* AApC publishing.

Bennett, K. D. (2016). The utility of single subject design research. *International Journal of Adult Vocational Education and Technology (IJAVET), 7*(2), 20-31.

Benton, L., & Johnson, H. (2015). Widening participation in technology design: A review of the involvement of children with special educational needs and disabilities. *International Journal of Child-Computer Interaction*, *3,* 23-40.

Bettencourt, C., Garret-Gloanec, N., Pellerin, H., Péré, M., Squillante, M., Roos-Weil, F., ... & Cohen, D. (2022). Migration is associated with baseline severity and progress over time in autism spectrum disorder: Evidence from a French prospective longitudinal study. *Plos one, 17*(10), e0272693.

Bharatharaj, J., Huang, L., Mohan, R. E., Al-Jumaily, A., & Krägeloh, C. (2017). Robot-assisted therapy for learning and social interaction of children with autism spectrum disorder. *Robotics*, *6*(1), 4.

Billeci, L., Narzisi, A., Tonacci, A., Sbriscia-Fioretti, B., Serasini, L., Fulceri, F., ... & Muratori, F. (2017). An integrated EEG and eye-tracking approach for the study of responding and initiating joint attention in Autism Spectrum Disorders. *Scientific Reports*, *7*(1), 13560.

Blanc R., Malvy J., Dansart P., Bataille M., Bonnet-Brilhault F., Barthélémy C. (2013). La thérapie d'échange et de développement, une rééducation neurofonctionnelle de la communication sociale. *Neuropsychiatrie de l'Enfance et de l'Adolescenc*e, *61* (5): 288-294.

Bonarini, A., Clasadonte, F., Garzotto, F., Gelsomini, M., & Romero, M. (2016, December). Playful interaction with Teo, a mobile robot for children with neurodevelopmental disorders. *In Proceedings of the 7th International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Info-exclusion* (pp. 223-231).

Bono, V., Narzisi, A., Jouen, A.-L., Tilmont, E., Hommel, S., Jamal, W., Xavier, J., Billeci, L., Maharatna, K., Wald, M., Chetouani, M., Cohen, D., Muratori, F., &MICHELANGELO Study Group. (2016). GOLIAH : A Gaming Platform for Home-Based Intervention in Autism – Principles and Design. *Frontiers in Psychiatry*, *7,*70.

Börjesson, P., Barendregt, W., Eriksson, E., & Torgersson, O. (2015, June). Designing technology for and with developmentally diverse children: a systematic literature review. *In Proceedings of the 14th international conference on interaction design and children* (pp. 79-88).

Boucenna, S., Anzalone, S., Tilmont, E., Cohen, D., & Chetouani, M. (2014). Learning of social signatures through imitation game between a robot and a human partner. *IEEE Transactions on Autonomous Mental Development*, *6*(3), 213-225.

Boucenna, S., Narzisi, A., Tilmont, E., Muratori, F., Pioggia, G., Cohen, D., & Chetouani, M. (2014). Interactive Technologies for Autistic Children : A Review. *Cognitive Computation*, *6*(4), 722-740. https://doi.org/10.1007/s12559-014-9276-x

Boulkedid, R., Abdoul, H., Loustau, M., Sibony, O., & Alberti, C. (2011). Using and reporting the Delphi method for selecting healthcare quality indicators: A systematic review. *PLoS One*, *6*(6), Article e20476.

Cabibihan, J. J., Javed, H., Ang, M., & Aljunied, S. M. (2013). Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism. *International journal of social robotics, 5,* 593-618.

Canady, V. A. (2020). FDA approves first video game Rx treatment for children with ADHD. *Mental Health Weekly*, *30*(26), 1-7.

Carlier, S., Van der Paelt, S., Ongenae, F., De Backere, F., & De Turck, F. (2020). Empowering children with ASD and their parents: Design of a serious game for anxiety and stress reduction. *Sensors*, *20*(4), 966. https://doi.org/10.3390/ s20040966

Charlop-Christy, M. H., Le, L., & Freeman, K. A. (2000). A comparison of video modeling with in vivo modeling for teaching children with autism. *Journal of autism and developmental disorders*, *30*, 537-552.

Charlop, M. H., & Milstein, J. P. (1989). Teaching autistic children conversational speech using video modeling. *Journal of applied behavior analysis*, *22*(3), 275-285.

Chevalier, P., Isableu, B., Martin, J. C., & Tapus, A. (2016). Individuals with autism: Analysis of the first interaction with nao robot based on their proprioceptive and kinematic profiles. *In Advances in Robot Design and Intelligent Control: Proceedings of the 24th International Conference on Robotics in Alpe-Adria-Danube Region (RAAD)* (pp. 225-233). Springer International Publishing.

Chevallier, C., Kohls, G., Troiani, V., Brodkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in cognitive sciences*, *16*(4), 231–239. https://doi.org/10.1016/j.tics.2012.02.007

Christensen, L., Hutman, T., Rozga, A., Young, G. S., Ozonoff, S., Rogers, S. J., ... & Sigman, M. (2010). Play and developmental outcomes in infant siblings of children with autism. *Journal of autism and developmental disorders*, *40,* 946-957.

Cifuentes, C. A., Pinto, M. J., Céspedes, N., & Múnera, M. (2020). Social robots in therapy and care. *Current Robotics Reports, 1,* 59-74.

Cirnigliaro, M., Chang, T. S., Arteaga, S. A., Pérez-Cano, L., Ruzzo, E. K., Gordon, A., ... & Geschwind, D. H. (2023). The contributions of rare inherited and polygenic risk to ASD in multiplex families. *Proceedings of the National Academy of Sciences*, *120*(31), e2215632120.

Cohen, D., Grossard, C., Grynszpan, O., Anzalone, S., Boucenna, S., Xavier, J., Chetouani, M., & Chaby, L. (2017). Autisme, jeux sérieux et robotique : Réalité tangible ou abus de langage ? *In Annales Médico-psychologiques, revue psychiatrique,* (Vol. 175, No. 5, pp. 438-445). Elsevier Masson.

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & education*, *59*(2), 661-686.

Costa, A. P., Charpiot, L., Lera, F. R., Ziafati, P., Nazarikhorram, A., van der Torre, L., & Steffgen, G. (2018). A comparison between a person and a robot in the attention, imitation, and repetitive and stereotypical behaviors of children with autism spectrum disorder. *In Proceedings workshop on Social human-robot interaction of human-care service robots at HRI2018* (pp. 1-4).

Dalton, C. (2016). Interaction design in the built environment: Designing for the 'Universal User'. *In Universal Design 2016: Learning From the Past, Designing for the Future* (pp. 314-323). IOS Press.

Dawe, J., Sutherland, C., Barco, A., & Broadbent, E. (2019). Can social robots help children in healthcare contexts? *A scoping review. BMJ paediatrics open*, *3*(1). https://doi.org/10.1136/bmjpo-2018-000371

Dawson, G., Rogers, S., Munson, J., Smith, M., Winter, J., & Greenson, J. (2010): Randomized, controlled trial of an intervention for toddlers with autism: The Early Start Denver Model. *Pediatrics*, *125*(1), e17-e23.

Dawson, G., Webb, S. J., Wijsman, E., Schellenberg, G., Estes, A., Munson, J., & Faja, S. (2005). Neurocognitive and electrophysiological evidence of altered face processing in parents of children with autism: Implications for a model of abnormal development of social brain circuitry in autism. *Development and psychopathology*, *17*(3), 679-697.

de Vries, M., Prins, P. J., Schmand, B. A., & Geurts, H. M. (2015). Working memory and cognitive flexibility-training for children with an autism spectrum disorder: A randomized controlled trial. *Journal of Child Psychology and Psychiatry*, *56*(5), 566-576.

Delobel-Ayoub, M., Ehlinger, V., Klapouszczak, D., Maffre, T., Raynaud, J. P., Delpierre, C., & Arnaud, C. (2015). Socioeconomic disparities and prevalence of autism spectrum disorders and intellectual disability. *PloS one*, *10*(11), e0141964.

Diamond, I. R., Grant, R. C., Feldman, B. M., Pencharz, P. B., Ling, S. C., Moore, A. M., & Wales, P. W. (2014). Defining consensus: A systematic review recommends methodologic criteria for reporting of Delphi studies. Journal of Clinical Epidemiology, *67*(4), 401–409.

Donard, V., & Simar, É. (2012). La médiation vidéo-ludique en psychothérapie. *Enfances Psy*, (2), 79-88.

Duquette, A., Michaud, F., & Mercier, H. (2008). Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. *Autonomous Robots, 24*(2), 147-157.

El Zein, F., Gevarter, C., Bryant, B., Son, S. H., Bryant, D., Kim, M., & Solis, M. (2016). A comparison between iPad-assisted and teacher-directed reading instruction for students with autism spectrum disorder (ASD). *Journal of Developmental and Physical Disabilities*, *28,* 195-215.

Elsabbagh, M., & Johnson, M. H. (2010). Getting answers from babies about autism. *Trends in cognitive sciences*, *14*(2), 81-87.

Esposito, A., Fortunati, L., & Lugano, G. (2014). Modeling emotion, behavior and context in socially believable robots and ICT interfaces. *Cognitive Computation*, *6,* 623-627.

Feil-Seifer, D., & Matarić, M. J. (2009, March). Toward socially assistive robotics for augmenting interventions for children with autism spectrum disorders. *In Experimental Robotics: The Eleventh International Symposium* (pp. 201-210). Berlin, Heidelberg: Springer Berlin Heidelberg.

Flores, E., Tobon, G., Cavallaro, E., Cavallaro, F. I., Perry, J. C., & Keller, T. (2008). Improving patient motivation in game development for motor deficit rehabilitation. *In Proceedings of the 2008 International Conference in Advances on Computer Entertainment Technology - ACE '08* (Vol. 7, p. 381).

Flores, M., Musgrove, K., Renner, S., Hinton, V., Strozier, S., Franklin, S., & Hil, D. (2012). A comparison of communication using the Apple iPad and a picture-based system. *Augmentative and Alternative Communication*, *28*(2), 74-84.

Foster, S. L., & Mash, E. J. (1999). Assessing social validity in clinical treatment research: issues and procedures. *Journal of consulting and clinical psychology*, 67(3), 308.

Francés, L., Quintero, J., Fernández, A., Ruiz, A., Caules, J., Fillon, G., ... & Soler, C. V. (2022). Current state of knowledge on the prevalence of neurodevelopmental disorders in childhood

according to the DSM-5: a systematic review in accordance with the PRISMA criteria. *Child and adolescent psychiatry and mental health*, *16*(1), 27.

Franceschini, S., Gori, S., Ruffino, M., Viola, S., Molteni, M., & Facoetti, A. (2013). Action video games make dyslexic children read better. *Current biology*, *23*(6), 462-466.

Frauenberger, C. (2015). Rethinking autism and technology. *Interactions*, *22*(2), 57–59. https://doi.org/10.1145/2728604

Freitas, D. Q., Da Gama, A. E. F., Figueiredo, L., Chaves, T. M., Marques-Oliveira, D., Teichrieb, V., & Araújo, C. (2012). Development and Evaluation of a Kinect Based Motor Rehabilitation Game. *In Proceedings of SBGames 2012* (Vol. 2012, pp. 144–153

Ganz, J. B., Boles, M. B., Goodwyn, F. D., & Flores, M. M. (2014). Efficacy of handheld electronic visual supports to enhance vocabulary in children with ASD. *Focus on Autism and Other Developmental Disabilities*, *29*(1), 3-12.

Ganz, J. B., Morin, K. L., Foster, M. J., Vannest, K. J., Genç Tosun, D., Gregori, E. V., & Gerow, S. L. (2017). High-technology augmentative and alternative communication for individuals with intellectual and developmental disabilities and complex communication needs: A meta-analysis. Augmentative and Alternative Communication, *33*(4), 224–https://doi.org/10.1080/07434618.2017.1373855

Gates, J. A., Kang, E., & Lerner, M. D. (2017). Efficacy of group social skills interventions for youth with autism spectrum disorder: A systematic review and meta-analysis. *Clinical psychology review*, *52,* 164-181.

Georgiades, S., Szatmari, P., Boyle, M., Hanna, S., Duku, E., Zwaigenbaum, L., ... & Pathways in ASD Study Team. (2013). Investigating phenotypic heterogeneity in children with autism spectrum disorder: a factor mixture modeling approach. *Journal of Child Psychology and Psychiatry*, *54*(2), 206-215.

Gevarter, C., O'Reilly, M. F., Rojeski, L., Sammarco, N., Sigafoos, J., Lancioni, G. E., & Lang, R. (2014). Comparing acquisition of AAC-based mands in three young children with autism spectrum disorder using iPad® applications with different display and design elements. *Journal of Autism and Developmental Disorders*, *44,* 2464-2474.

Gliga, T., Jones, E. J., Bedford, R., Charman, T., & Johnson, M. H. (2014). From early markers to neuro-developmental mechanisms of autism. *Developmental Review*, *34*(3), 189-207.

Golan, O., & Baron-Cohen, S. (2006). Systemizing empathy: Teaching adults with Asperger syndrome or high-functioning autism to recognize complex emotions using interactive multimedia. *Development and psychopathology*, *18*(2), 591-617.

Goods, K. S., Ishijima, E., Chang, Y. C., & Kasari, C. (2013). Preschool based JASPER intervention in minimally verbal children with autism: Pilot RCT. *Journal of autism and developmental disorders*, *43,* 1050-1056.

Gosling, C. J., Cartigny, A., Mellier, B. C., Solanes, A., Radua, J., & Delorme, R. (2022). Efficacy of psychosocial interventions for Autism spectrum disorder: An umbrella review. *Molecular Psychiatry*, *27*(9), 3647-3656.

Greenspan, S. I., & Wieder, S. (2006). *Engaging autism: Using the floortime approach to help children relate, communicate, and think.* Da Capo Lifelong Books.

Grossard, C., Bettencourt, C., Kellems, R., Chetouani, M., & Cohen, D. (2023). Building the design ICT inventory (DICTI): A Delphi study. *Computers in Human Behavior Reports*, 9, 100261.

Grossard, C., Grynspan, O., Serret, S., Jouen, A. L., Bailly, K., & Cohen, D. (2017). Serious games to teach social interactions and emotions to individuals with autism spectrum disorders (ASD). *Computers & Education*, 113, 195–211. https://doi.org/ 10.1016/j.compedu.2017.05.002

Grossard, C., Palestra, G., Xavier, J., Chetouani, M., Grynszpan, O., & Cohen, D. (2018). ICT and autism care: state of the art. *Current opinion in psychiatry*, *31*(6), 474-483.

Grynszpan, O., Weiss, P. L., Perez-Diaz, F., & Gal, E. (2014). Innovative technology-based interventions for autism spectrum disorders: a meta-analysis. *Autism*, *18*(4), 346-361.

Guard, A., Konz, M., Smith, R. O., Engel, J. M., & Keating, T. (2019). The development of an iPad application for the pain assessment of individuals with developmental disabilities and complex communication needs. *Assistive Technology*, 1–12. https:// doi.org/10.1080/10400435.2019.1612797

Guinchat, V., Thorsen, P., Laurent, C., Cans, C., Bodeau, N., & Cohen, D. (2012). Pre-, peri-and neonatal risk factors for autism. *Acta obstetricia et gynecologica Scandinavica*, 91(3), 287-300.

Gyori, M., Stefanik, K., & Kanizsai-Nagy, I. (2015). Evidence-based development and evaluation of mobile cognitive support apps for people on the autism spectrum: Methodological conclusions from two R+ D projects. August. *In AAATE Conf.* (pp. 55–62).

Autorité de Santé, H. A. (2011). Autisme et autres troubles envahissants du développement: interventions éducatives et thérapeutiques coordonnées chez l'enfant et l'adolescent. *Repéré à http://www.has-sante.fr/portail/upload/docs/application/pdf/20107/autisme_enfant_reco2clics_vd.*

Hollis, C., & Glazebrook, C. (2019). The effectiveness of web-based interventions delivered to children and young people with neurodevelopmental disorders: Systematic review and meta-analysis. *Journal of Medical Internet Research*, *21*(11), Article e13478. https://doi.org/10.2196/13478

Hollis, C., Falconer, C. J., Martin, J. L., Whittington, C., Stockton, S., Glazebrook, C., & Davies, E. B. (2017). Annual Research Review: Digital health interventions for children and young people with mental health problems–a systematic and meta-review. *Journal of Child Psychology and Psychiatry, 58*(4), 474–503. https://doi.org/ 10.1111/jcpp.12663

Horn, J. A., Miltenberger, R. G., Weil, T., Mowery, J., Conn, M., & Sams, L. (2008). Teaching laundry skills to individuals with developmental disabilities using video prompting. *International Journal of Behavioral Consultation and Therapy*, *4*(3), 279.

Husereau, D., Drummond, M., Petrou, S., Carswell, C., Moher, D., Greenberg, D., ... & Loder, E. (2013). Consolidated health economic evaluation reporting standards (CHEERS) statement. *International journal of technology assessment in health care*, *29*(2), 117-122.

Huskens, B., Palmen, A., Van der Werff, M., Lourens, T., & Barakova, E. (2015). Improving collaborative play between children with autism spectrum disorders and their siblings: The effectiveness of a robot-mediated intervention based on Lego® therapy. *Journal of autism and developmental disorders*, 45, 3746-3755.

Hyman, S. L., Levy, S. E., Myers, S. M., Kuo, D. Z., Apkon, S., Davidson, L. F., ... & Bridgemohan, C. (2020). Identification, evaluation, and management of children with autism spectrum disorder. *Pediatrics*, *145*(1).

Ismail, L. I., Verhoeven, T., Dambre, J., & Wyffels, F. (2019). Leveraging robotics research for children with autism: a review. *International Journal of Social Robotics*, *11,* 389-410.

Jordan, K., King, M., Hellersteth, S., Wirén, A., & Mulligan, H. (2012, July). Robotic technology for teaching adolescents with autism spectrum disorder: a feasibility study. *In Proceedings of the 6th International Conference on Rehabilitation Engineering & Assistive Technology* (pp. 1-4).

Jorm, A. F. (2015). Using the Delphi expert consensus method in mental health research. *Australian and New Zealand Journal of Psychiatry*, *49*(10), 887–897. https://doi.org/ 10.1177/0004867415600891

Jouen, A. L., Narzisi, A., Xavier, J., Tilmont, E., Bodeau, N., Bono, V., ... & Cohen, D. (2017). GOLIAH (Gaming Open Library for Intervention in Autism at Home): a 6-month single blind matched controlled exploratory study. *Child and adolescent psychiatry and mental health, 11*(1), 1-14.

Kaloudi, N., & Li, J. (2021). Comparison of risk analysis approaches for analyzing emergent misbehavior in autonomous systems. *In Proceedings of the 31st European Safety and Reliability Conference ESREL.*

Khan, K., Hall, C. L., Davies, E. B., Hollis, C., & Glazebrook, C. (2019). The Effectiveness of Web-Based Interventions Delivered to Children and Young People With Neurodevelopmental Disorders: Systematic Review and Meta-Analysis. *Journal of medical Internet, 21*(11), e13478.

Kim, E. S., Berkovits, L. D., Bernier, E. P., Leyzberg, D., Shic, F., Paul, R., & Scassellati, B. (2013). Social robots as embedded reinforcers of social behavior in children with autism. *Journal of autism and developmental disorders, 43,* 1038-1049

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., ... & Westerberg, H. (2005). Computerized training of working memory in children with ADHD-a randomized, controlled trial. *Journal of the American Academy of child & adolescent psychiatry, 44*(2), 177-186.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of clinical and experimental neuropsychology, 24*(6), 781-791.

Knight, V., McKissick, B. R., & Saunders, A. (2013). A review of technology-based interventions to teach academic skills to students with autism spectrum disorder. *Journal of autism and developmental disorders, 43*, 2628-2648.

Kokol, P., Vošner, H. B., Završnik, J., Vermeulen, J., Shohieb, S., & Peinemann, F. (2020). Serious game-based intervention for children with developmental disabilities. *Current pediatric reviews, 16(1*), 26-32.

Kolevzon, A., Gross, R., & Reichenberg, A. (2007). Prenatal and perinatal risk factors for autism: a review and integration of findings. *Archives of pediatrics & adolescent medicine, 161*(4), 326-333.

Kollins, S. H., DeLoss, D. J., Cañadas, E., Lutz, J., Findling, R. L., Keefe, R. S., ... & Faraone, S. V. (2020). A novel digital intervention for actively reducing severity of paediatric ADHD (STARS-ADHD): a randomised controlled trial. *The Lancet Digital Health, 2*(4), e168-e178.

Kostrubiec, V., & Kruck, J. (2020). Collaborative research project: Developing and testing a robot-assisted intervention for children with autism. *Frontiers in Robotics and AI, 7*, 37.

Kouroupa, A., Laws, K. R., Irvine, K., Mengoni, S. E., Baird, A., & Sharma, S. (2022). The use of social robots with children and young people on the autism spectrum: A systematic review and meta-analysis. *Plos one, 17*(6), e0269800.

Kozima, H., Nakagawa, C., & Yasuda, Y. (2005, August). Interactive robots for communication-care: A case-study in autism therapy. *In ROMAN 2005. IEEE International Workshop on Robot and Human Interactive Communication, 2005.* (pp. 341-346). IEEE.

Kruck, J., Séjourné, N., Rogé, B., & Courty, S. (2017). Étude sur l'efficacité des groupes d'habiletés sociales proposés aux enfants avec un trouble du spectre autistique. *Journal de thérapie comportementale et cognitive, 27*(1), 25-33. https://doi.org/10.1016/j.jtcc.2016.09.002

Kumazaki, H., Muramatsu, T., Yoshikawa, Y., Matsumoto, Y., Ishiguro, H., Kikuchi, M., ... & Mimura, M. (2020). Optimal robot for intervention for individuals with autism spectrum disorders. *Psychiatry and Clinical Neurosciences, 74*(11), 581-586.

Kumazaki, H., Yoshikawa, Y., Yoshimura, Y., Ikeda, T., Hasegawa, C., Saito, D. N., ... & Kikuchi, M. (2018). The impact of robotic intervention on joint attention in children with autism spectrum disorders. *Molecular autism, 9*(1), 1-10.

Langer, A., Feingold-Polak, R., Mueller, O., Kellmeyer, P., & Levy-Tzedek, S. (2019). Trust in socially assistive robots: Considerations for use in rehabilitation. *Neuroscience & Biobehavioral Reviews, 104*, 231–239. https://doi.org/10.1016/j. neubiorev.2019.07.014

Langlois, J. H., Roggman, L. A., & Rieser-Danner, L. A. (1990). Infants' differential social responses to attractive and unattractive faces. *Developmental psychology*, *26*(1), 153.

LaSalle, J. M., Vallero, R. O., & Mitchell, M. M. (2013). Epigenetics at the interface of genetics and environmental factors in autism. Environmental Epigenomics in Health and Disease: *Epigenetics and Complex Diseases, 97*-114.

Lecciso, F., Levante, A., Fabio, R. A., Caprì, T., Leo, M., Carcagnì, P., ... & Petrocchi, S. (2021). Emotional expression in children with ASD: a pre-study on a two-group pre-post-test design comparing robot-based and computer-based training. *Frontiers in psychology, 12*, 678052.

Leite, I., Martinho, C., Pereira, A., & Paiva, A. (2009, September). As time goes by: Long-term evaluation of social presence in robotic companions. *In RO-MAN 2009- the 18th IEEE international symposium on robot and human interactive communication* (pp. 669-674). IEEE.

Liang, J., & Wilkinson, K. (2018). Gaze toward naturalistic social scenes by individuals with intellectual and developmental disabilities: Implications for augmentative and alternative communication designs. *Journal of Speech, Language, and Hearing Research, 61*(5), 1157–1170. https://doi.org/10.1044/2018_JSLHR-L-17-0331

Lichtenstein, P., Carlström, E., Råstam, M., Gillberg, C., & Anckarsäter, H. (2010). The genetics of autism spectrum disorders and related neuropsychiatric disorders in childhood. *American Journal of Psychiatry, 167*(11), 1357-1363.

Light, J., & McNaughton, D. (2012). Supporting the communication, language, and literacy development of children with complex communication needs: State of the science and future research priorities. *Assistive Technology, 24*(1), 34–44. https://doi. org/10.1080/10400435.2011.648717

Light, J., McNaughton, D., & Caron, J. (2019). New and emerging AAC technology supports for children with complex communication needs and their communication partners: State of the science and future research directions. *Augmentative and Alternative Communication, 35*(1), 26-41.

Litras, S., Moore, D. W., & Anderson, A. (2010). Using video self-modelled social stories to teach social skills to a young child with autism. *Autism research and treatment, 2010.*

Liu, R., Salisbury, J. P., Vahabzadeh, A., & Sahin, N. T. (2017). Feasibility of an autism-focused augmented reality smartglasses system for social communication and behavioral coaching. *Frontiers in pediatrics, 5,* 145.

Lorah, E. R., Parnell, A., Whitby, P. S., & Hantula, D. (2015). A systematic review of tablet computers and portable media players as speech generating devices for individuals with autism spectrum disorder. *Journal of autism and developmental disorders, 45*, 3792-3804.

Lord, C., Brugha, T. S., Charman, T., Cusack, J., Dumas, G., Frazier, T., ... & Veenstra-VanderWeele, J. (2020). Autism spectrum disorder. *Nature reviews Disease primers, 6*(1), 1-23.

Lord, C., Rutter, M., DiLavore, P., Risi, S., Gotham, K., & Bishop, S. (2012). Autism diagnostic observation schedule–2nd edition (ADOS-2). *Los Angeles, CA: Western Psychological Corporation, 284.*

Maskey, M., Rodgers, J., Grahame, V., Glod, M., Honey, E., Kinnear, J., ... & Parr, J. R. (2019). A randomised controlled feasibility trial of immersive virtual reality treatment with cognitive behaviour therapy for specific phobias in young people with autism spectrum disorder. *Journal of autism and developmental disorders, 49*, 1912-1927.

Mazon, C., & Sauzéon, H. (2021). Utilisation des technologies mobiles auprès des enfants avec TSA.

Mazon, C., Fage, C., & Sauzéon, H. (2019). Effectiveness and usability of technology-based interventions for children and adolescents with ASD: A systematic review of reliability, consistency, generalization and durability related to the effects of intervention. *Computers in Human Behavior, 93*, 235-251.

McCarty, P., & Frye, R. E. (2020, October). Early detection and diagnosis of autism spectrum disorder: why is it so difficult?. *In Seminars in Pediatric Neurology* (Vol. 35, p. 100831). WB Saunders.

McMahon, C. M., Vismara, L. A., & Solomon, M. (2013). Measuring changes in social behavior during a social skills intervention for higher-functioning children and adolescents with autism spectrum disorder. *Journal of autism and developmental disorders, 43,* 1843-1856.

Mélia, G., Di Loreto, I., Salembier, P., Seilles, A., & Tallon, G. (2014). Évaluation d'un jeu sérieux thérapeutique. *In SeGaMed 2014: Le serious game au service de la santé.*

Miguel Cruz, A., Rios Rincon, A. M., Rodriguez Duenas, W. R., Quiroga Torres, D. A., & Bohorquez-Heredia, A. F. (2017). What does the literature say about using robots on children with disabilities? Disability and Rehabilitation: *Assistive Technology, 12*(5), 429–440. https://doi.org/10.1080/17483107.2017.1318308

Mitchell, P., Parsons, S., & Leonard, A. (2007). Using virtual environments for teaching social understanding to 6 adolescents with autistic spectrum disorders. *Journal of autism and developmental disorders, 37*, 589-600.

Mitchell, S., Cardy, J. O., & Zwaigenbaum, L. (2011). Differentiating autism spectrum disorder from other developmental delays in the first two years of life. *Developmental disabilities research reviews, 17*(2), 130-140.

Moon, S. J., Hwang, J., Hill, H. S., Kervin, R., Birtwell, K. B., Torous, J., … _Kim, J. W. (2020). Mobile device applications and treatment of autism spectrum disorder: A systematic review and meta-analysis of effectiveness. *Archives of Disease in Childhood, 105*(5), 458–462. https://doi.org/10.1136/archdischild-2019-318258

Moore, D., McGrath, P., & Thorpe, J. (2000). Computer-aided learning for people with autism–a framework for research and development. *Innovations in education and training international, 37*(3), 218-228.

Morin, K. L., Ganz, J. B., Gregori, E. V., Foster, M. J., Gerow, S. L., Genç-Tosun, D., & Hong, E. R. (2018). A systematic quality review of high-tech AAC interventions as an evidence-based practice. *Augmentative and Alternative Communication, 34*(2),104–117. https://doi.org/10.1080/07434618.2018.1458900

Narzisi, A., Costanza, C., Umberto, B., & Filippo, M. (2014). Non-pharmacological treatments in autism spectrum disorders: an overview on early interventions for pre-schoolers. *Current clinical pharmacology, 9*(1), 17-26.

Neary, M., & Schueller, S. M. (2018). State of the field of mental health apps. *Cognitive and Behavioral Practice, 25*(4), 531-537.

Nielsen, J. (1994, April). Usability inspection methods. *In Conference companion on Human factors in computing systems* (pp. 413-414).

Odom, S. L., Thompson, J. L., Hedges, S., Boyd, B. A., Dykstra, J. R., Duda, M. A., … _Bord, A. (2015). Technology-aided interventions and instruction for adolescents with autism

spectrum disorder. *Journal of Autism and Developmental Disorders, 45(*12), 3805–3819. https://doi.org/10.1007/s10803-014-2320-6

Oertel, C., Castellano, G., Chetouani, M., Nasir, J., Obaid, M., Pelachaud, C., & Peters, C. (2020). Engagement in human-agent interaction: An overview. *Frontiers in Robotics and AI, 7*, 92.

Ooki, S. (2005). Genetic and environmental influences on finger-sucking and nail-biting in Japanese twin children. *Twin Research and Human Genetics, 8*(4), 320-327.

Park, H. W., Gelsomini, M., Lee, J. J., & Breazeal, C. (2017, March). Telling stories to robots: The effect of backchanneling on a child's storytelling. *In Proceedings of the 2017 ACM/IEEE international conference on human-robot interaction* (pp. 100-108).

Park, J., Bouck, E., & Duenas, A. (2019). The effect of video modeling and video prompting interventions on individuals with intellectual disability: A systematic literature review. Journal of Special Education Technology, 34(1), 3-16.

Park, M. J., Kim, D. J., Lee, U., Na, E. J., & Jeon, H. J. (2019). A literature overview of virtual reality (VR) in treatment of psychiatric disorders: Recent advances and limitations. *Frontiers in Psychiatry, 10, 505*. https://doi.org/10.3389/ fpsyt.2019.00505.

Parsons, D., Wilson, N. J., Vaz, S., Lee, H., & Cordier, R. (2019). Appropriateness of the TOBY application, an iPad intervention for children with autism spectrum disorder: A thematic approach. *Journal of Autism and Developmental Disorders, 49(*10), 4053–4066. https://doi.org/10.1007/s10803-019-04115-9.

Parsons, S., & Cobb, S. (2014). Reflections on the role of the 'users': Challenges in a multi-disciplinary context of learner-centred design for children on the autism spectrum. *International Journal of Research and Method in Education, 37*(4), 421–441. https://doi.org/10.1080/1743727X.2014.890584

Pennisi, P., Tonacci, A., Tartarisco, G., Billeci, L., Ruta, L., Gangemi, S., & Pioggia, G. (2016). Autism and social robotics: A systematic review. *Autism Research, 9*(2), 165-183.

Perrin, J. (2011). Le jeu chez les enfants avec autisme. *Autisme et Jeu: apprendre à jouer avec la personne autiste*, 21-36.

Pickles, A., Le Couteur, A., Leadbitter, K., Salomone, E., Cole-Fletcher, R., Tobin, H., ... & Green, J. (2016). Parent-mediated social communication therapy for young children with

autism (PACT): long-term follow-up of a randomised controlled trial. *The Lancet, 388*(10059), 2501-2509.

Pickles, A., McCauley, J. B., Pepa, L. A., Huerta, M., & Lord, C. (2020). The adult outcome of children referred for autism: typology and prediction from childhood. *Journal of Child Psychology and Psychiatry, 61*(7), 760-767.

Pioggia, G., Sica, M. L., Ferro, M., Igliozzi, R., Muratori, F., Ahluwalia, A., & De Rossi, D. (2007, August). Human-robot interaction in autism: FACE, an android-based social therapy. *In RO-MAN 2007-the 16th IEEE international symposium on robot and human interactive communication* (pp. 605-612). IEEE.

Polisena, J., Castaldo, R., Ciani, O., Federici, C., Borsci, S., Ritrovato, M., … _Pecchia, L. (2018). Health technology assessment methods guidelines for medical devices: How can we address the gaps? The international federation of medical and biological engineering perspective. *International Journal of Technology Assessment in Health Care, 34*(3), 276–289. https://doi.org/10.1017/S0266462318000314

Powell, C. (2003). The Delphi technique: Myths and realities. *Journal of Advanced Nursing, 41*(4), 376–382. https://doi.org/10.1046/j.1365-2648.2003.02537.x

Powell, L., Parker, J., Harpin, V., & Mawson, S. (2019). Guideline development for technological interventions for children and young people to self-manage attention deficit hyperactivity disorder: realist evaluation. *Journal of medical Internet research, 21*(4), e12831.

Puglisi, A., Caprì, T., Pignolo, L., Gismondo, S., Chilà, P., Minutoli, R., Marino, F., Failla, C., Arnao, A. A., Tartarisco, G., Cerasa, A., & Pioggia, G. (2022). Social Humanoid Robots for Children with Autism Spectrum Disorders: A Review of Modalities, Indications, and Pitfalls. *Children, 9*(7), 953. https://doi.org/10.3390/children9070953

Quezada, A., Juárez-Ramírez, R., Jiménez, S., Noriega, A. R., Inzunza, S., & Garza, A. A. (2017). Usability operations on touch mobile devices for users with autism. *Journal of medical systems, 41,* 1-11.

Quill, K. A. (1997). Instructional considerations for young children with autism: The rationale for visually cued instruction. *Journal of autism and developmental disorders, 27*(6), 697-714.

Rangasamy, S., D'Mello, S. R., & Narayanan, V. (2013). Epigenetics, Autism Spectrum, and Neurodevelopmental Disorders. *Neurotherapeutics, 10*(4), 742.

Rao, P. A., Beidel, D. C., & Murray, M. J. (2008). Social skills interventions for children with Asperger's syndrome or high-functioning autism: A review and recommendations. *Journal of autism and developmental disorders, 38*, 353-361.

Rattaz, C., Munir, K., Michelon, C., Picot, M. C., & Baghdadli, A. (2020). School inclusion in children and adolescents with autism spectrum disorders in France: report from the ELENA French Cohort Study. *Journal of Autism and Developmental Disorders, 50,* 455-466.

Rego, P., Moreira, P. M., & Reis, L. P. (2010, June). Serious games for rehabilitation: A survey and a classification towards a taxonomy. *In Information Systems and Technologies (CISTI), 2010 5th Iberian Conference on* (pp. 1-6). IEEE.

Reichle, J., & Ward, M. (1985). Teaching discriminative use of an encoding electronic communication device and signing exact English to a moderately handicapped child. *Language, Speech, and Hearing Services in Schools, 16*(1), 58-63.

Reichow, B., Steiner, A. M., & Volkmar, F. (2012). Social skills groups for people aged 6 to 21 with autism spectrum disorders (ASD). *Campbell Systematic Reviews, 8*(1), 1-76.

Richardson, K., Coeckelbergh, M., Wakunuma, K., Billing, E., Ziemke, T., Gomez, P., ... & Belpaeme, T. (2018). Robot enhanced therapy for children with autism (DREAM): A social model of autism. *IEEE Technology and society magazine, 37*(1), 30-39.

Rietz, F., Sutherland, A., Bensch, S., Wermter, S., & Hellström, T. (2021). WoZ4U: an open-source wizard-of-oz interface for easy, efficient and robust HRI experiments. *Frontiers in Robotics and AI, 8*, 668057.

Robins, B., Dautenhahn, K., Boekhorst, R. T., & Billard, A. (2005). Robotic assistants in therapy and education of children with autism: can a small humanoid robot help encourage social interaction skills?. *Universal access in the information society, 4*, 105-120.

Romero, M., Bonarini, A., Brivio, A., & Rogacheva, K. (2017). Incremental and Radical Innovation: Design in Robotics for Autism. Teo and Riby robots. *Evolutionary Development. The Design Journal, 20*(sup1), S2375-S2388.

Root, J. R., Stevenson, B. S., Davis, L. L., Geddes-Hall, J., & Test, D. W. (2017). Establishing computer-assisted instruction to teach academics to students with autism as an evidence-based practice. *Journal of Autism and Developmental Disorders, 47*, 275-284.

Rutter, M., Le Couteur, A., & Lord, C. (2003). ADI-R. Autism diagnostic interview revised. *Manual. Los Angeles: Western Psychological Services.*

Saito, M., Hirota, T., Sakamoto, Y., Adachi, M., Takahashi, M., Osato-Kaneda, A., ... & Nakamura, K. (2020). Prevalence and cumulative incidence of autism spectrum disorders and the patterns of co-occurring neurodevelopmental disorders in a total population sample of 5-year-old children. *Molecular autism, 11*(1), 1-9.

Saleh, M. A., Hanapiah, F. A., & Hashim, H. (2021). Robot applications for autism: a comprehensive review. Disability and Rehabilitation: *Assistive Technology, 16*(6), 580-602.

Salomone, E., Beranová, Š., Bonnet-Brilhault, F., Briciet Lauritsen, M., Budisteanu, M., Buitelaar, J., ... & Charman, T. (2016). Use of early intervention for young children with autism spectrum disorder across Europe. *Autism, 20*(2), 233-249.

Sandbank, M., Bottema-Beutel, K., Crowley, S., Cassidy, M., Dunham, K., Feldman, J. I., ... & Woynaroski, T. G. (2020). Project AIM: Autism intervention meta-analysis for studies of young children. *Psychological bulletin, 146*(1), 1.

Sandgreen, H., Frederiksen, L. H., & Bilenberg, N. (2021). Digital interventions for autism spectrum disorder: a meta-analysis. *Journal of Autism and Developmental Disorders, 51,* 3138-3152.

Sandin, S., Lichtenstein, P., Kuja-Halkola, R., Larsson, H., Hultman, C. M., & Reichenberg, A. (2014). The familial risk of autism. *Jama, 311*(17), 1770-1777.

Sartorato, F., Przybylowski, L., & Sarko, D. K. (2017). Improving therapeutic outcomes in autism spectrum disorders: Enhancing social communication and sensory processing through the use of interactive robots. *Journal of psychiatric research, 90,* 1-11.

Scassellati, B., Admoni, H., & Matarić, M. (2012). Robots for use in autism research. *Annual review of biomedical engineering, 14,* 275-294.

Scassellati, B., Boccanfuso, L., Huang, C. M., Mademtzi, M., Qin, M., Salomons, N., ... & Shic, F. (2018). Improving social skills in children with ASD using a long-term, in-home social robot. *Science Robotics, 3*(21), eaat7544.

Schadenberg, B. R., Reidsma, D., Heylen, D. K., & Evers, V. (2020). Differences in spontaneous interactions of autistic children in an interaction with an adult and humanoid robot. *Frontiers in Robotics and AI, 7*, 28.

Schröder, C. M., Florence, E., Dubrovskaya, A., Lambs, B., Stritmatter, P., Vecchionacci, V., ... & Danion-Grilliat, A. (2015). Le modèle de Denver (Early Start Denver Model). Une approche d'intervention précoce pour les troubles du spectre autistique. *Neuropsychiatrie de l'Enfance et de l'Adolescence, 63*(5), 279-287.

Schultz, R. A. (Ed.). (2005). *Contemporary issues in ethics and information technology.* IGI Global.

Serret, S., Hun, S., Iakimova, G., Lozada, J., Anastassova, M., Santos, A., ... & Askenazy, F. (2014). Facing the challenge of teaching emotions to individuals with low-and high-functioning autism using a new serious game: a pilot study. *Molecular autism, 5*(1), 1-17.

Sidner, C. L., Lee, C., Kidd, C. D., Lesh, N., & Rich, C. (2005). Explorations in engagement for humans and robots. *Artificial Intelligence, 166*(1-2),140 https://doi.org/10.1016/j.artint.2005.03.005

Skantze, G. (2021). Turn-taking in conversational systems and human-robot interaction: a review. *Computer Speech & Language, 67,* 101178.

Solmi, M., Radua, J., Olivola, M., Croce, E., Soardo, L., de Pablo, G. S., ... & Fusar-Poli, P. (2022). Age at onset of mental disorders worldwide: large-scale meta-analysis of 192 epidemiological studies. *Molecular Psychiatry, 27(1),* 281-295.

Spiel, K., Frauenberger, C., Keyes, O., & Fitzpatrick, G. (2019). Agency of autistic children in technology research—A critical literature review. ACM *Transactions on Computer-Human Interaction (TOCHI), 26*(6), 1-40.

Spriggs, A. D., Knight, V., & Sherrow, L. (2015). Talking picture schedules: Embedding video models into visual activity schedules to increase independence for students with ASD. *Journal of autism and developmental disorders, 45*, 3846-3861.

Steinbrenner, J. R., Hume, K., Odom, S. L., Morin, K. L., Nowell, S. W., Tomaszewski, B., ... & Savage, M. N. (2020). Evidence-Based Practices for Children, Youth, and Young Adults with Autism. *FPG child development institute.*

Steinfeld, A., Jenkins, O. C., & Scassellati, B. (2009, March). The oz of wizard: simulating the human for interaction research. *In Proceedings of the 4th ACM/IEEE international conference on Human robot interaction* (pp. 101-108).

Strain, P. S., Barton, E. E., & Dunlap, G. (2012). Lessons learned about the utility of social validity. *Education and Treatment of Children, 183*-200.

Strickland, D. (1997). Virtual reality for the treatment of autism. *Virtual reality in neuro-psycho-physiology, 81*-86.

Strickland, D. C., McAllister, D., Coles, C. D., & Osborne, S. (2007). An evolution of virtual reality training designs for children with autism and fetal alcohol spectrum disorders. *Topics in language disorders, 27*(3), 226.

Stumpp, N. E., & Sauer-Zavala, S. (2022). Evidence-based strategies for treatment personalization: A review. *Cognitive and Behavioral Practice, 29*(4), 902-913.

Sung, J., Christensen, H. I., & Grinter, R. E. (2009, March). Robots in the wild: understanding long-term use. *In Proceedings of the 4th ACM/IEEE international conference on Human robot interaction* (pp. 45-52).

Taheri, A., Meghdari, A., Alemi, M., & Pouretemad, H. (2018). Human–robot interaction in autism treatment: a case study on three pairs of autistic children as twins, siblings, and classmates. *International Journal of Social Robotics, 10,* 93-113.

Tang, J. S., Falkmer, M., Chen, N. T., Bölte, S., & Girdler, S. (2019). Designing a serious game for youth with ASD: perspectives from end-users and professionals. *Journal of autism and developmental disorders, 49*, 978-995.

Temple, E., Deutsch, G. K., Poldrack, R. A., Miller, S. L., Tallal, P., Merzenich, M. M., & Gabrieli, J. D. (2003). Neural deficits in children with dyslexia ameliorated by behavioral remediation: evidence from functional MRI. *Proceedings of the National Academy of Sciences, 100*(5), 2860-2865.

Thapar, A., & Rutter, M. (2015). Using natural experiments and animal models to study causal hypotheses in relation to child mental health problems. *Rutter's child and adolescent psychiatry, 143*-162.

Tisseron, S., & Tordo, F. (2018). *Robots, de nouveaux partenaires de soins psychiques.* Érès.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and brain sciences, 28*(5), 675-691.

Tozadore D., Pinto A., Romero R., & Trovato G. (2017). Wizard of Oz vs autonomous: Children's perception changes according to robot's operation condition. *In 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)* (pp. 664-669).

Tseng, A., Biagianti, B., Francis, S. M., Conelea, C. A., & Jacob, S. (2020). Social Cognitive Interventions for Adolescents with Autism Spectrum Disorders: A Systematic Review. *Journal of Affective Disorders, 274,* 199-204.

Tsikinas, S., Xinogalos, S., Satratzemi, M., & Kartasidou, L. (2019,October). Designing a serious game for independent living skills in specialeducation. *In European Conference on Games Based Learning (pp. 748XXIII).* Academic Conferences International Limited.

Valentine, A. Z., Brown, B. J., Groom, M. J., Young, E., Hollis, C., & Hall, C. L. (2020). A systematic review evaluating the implementation of technologies to assess, monitor and treat neurodevelopmental disorders: A map of the current evidence. *Clinical Psychology Review*, *80* 101870.

Virues-Ortega, J., Julio, F. M., & Pastor-Barriuso, R. (2013). The TEACCH program for children and adults with autism: A meta-analysis of intervention studies. *Clinical psychology review, 33*(8), 940-953.

Vivanti, G., Prior, M., Williams, K., & Dissanayake, C. (2014). Predictors of outcomes in autism early intervention: why don't we know more?. *Frontiers in pediatrics, 2*, 58.

Wainer, J., Robins, B., Amirabdollahian, F., & Dautenhahn, K. (2014). Using the humanoid robot KASPAR to autonomously play triadic games and facilitate collaborative play among children with autism. *IEEE Transactions on Autonomous Mental Development, 6*(3), 183-199.

Waldman-Levi, A., Golisz, K., Swierat, R. P., & Toglia, J. (2019). Scoping review: Interventions that promote functional performance for adolescents and adults with Intellectual and Developmental Disabilities. *Australian Occupational Therapy Journal, 66*(4), 458-468.

Warren, Z., McPheeters, M. L., Sathe, N., Foss-Feig, J. H., Glasser, A., & Veenstra-VanderWeele, J. (2011). A systematic review of early intensive intervention for autism spectrum disorders. *Pediatrics, 127*(5), e1303-e1311.

Werner, E., Dawson, G., Munson, J., & Osterling, J. (2005). Variation in Early Developmental Course in Autism and its Relation with Behavioral Outcome at 3-4 Years of Age. *Journal of Autism and Developmental Disorders, 35*(3), 337.

Whyte, E. M., Smyth, J. M., & Scherf, K. S. (2015). Designing serious game interventions for individuals with autism. *Journal of autism and developmental disorders*, *45*, 3820-3831.

Wigelsworth, M., Humphrey, N., Kalambouka, A., & Lendrum, A. (2010). A review of key issues in the measurement of children's social and emotional skills. *Educational Psychology in Practice, 26*(2), 173-186. https://doi.org/10.1080/02667361003768526

Wolff, J. J., Botteron, K. N., Dager, S. R., Elison, J. T., Estes, A. M., Gu, H., ... & IBIS Network. (2014). Longitudinal patterns of repetitive behavior in toddlers with autism. *Journal of Child Psychology and Psychiatry, 55(*8), 945-953.

Wong, C., Odom, S. L., Hume, K. A., Cox, A. W., Fettig, A., Kucharczyk, S., ... & Schultz, T. R. (2015). Evidence-based practices for children, youth, and young adults with autism spectrum disorder: A comprehensive review. *Journal of autism and developmental disorders, 45,* 1951-1966.

World Health Organization. (2019). *The WHO special initiative for mental health (2019-2023): universal health coverage for mental health* (No. WHO/MSD/19.1). World Health Organization.

Xavier, J., & Cohen, D. (2020). Multidimensional impairments. *Handbook of Clinical Neurology, 174*, 159-169.

Yun, S. S., Choi, J., Park, S. K., Bong, G. Y., & Yoo, H. (2017). Social skills training for children with autism spectrum disorder using a robotic behavioral intervention system. *Autism Research, 10*(7), 1306-1323.

Zervogianni, V., Fletcher-Watson, S., Herrera, G., Goodwin, M., Pérez-Fuster, P., Brosnan, M., & Grynszpan, O. (2020). A framework of evidence-based practice for digital support, co-developed with and for the autism community. *Autism*, *24*(6), 1411-1422.

Zou, J., Gauthier, S., Anzalone, S. M., Cohen, D., & Archambault, D. (2022, July). A wizard of oz interface with qtrobot for facilitating the handwriting learning in children with dysgraphia and its usability evaluation. *In International Conference on Computers Helping People with Special Needs* (pp. 219-225). Cham: Springer International Publishing.

Zou, J., Gauthier, S., APHP, P. S., Archambault, D., Anzalone, S. M., & Cohen, D. (2021). THE IRECHECK PROJECT-Asocial ROBOT HELPING.

Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., & Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. *International journal of developmental neuroscience, 23*(2-3), 143-152.

# *Appendix*

1. **Supplementary material related to chapter 3, from:**

**Grossard, C., Bettencourt, C., Kellems, R., Chetouani, M., & Cohen, D. (2023). Building the design ICT inventory (DICTI): A Delphi study. *Computers in Human Behavior Reports*,*9*,100261.**

*Supplementary material*

DICTI version 1: round 1

| Features and Targeted skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| 1. Possible customization by the user<br><br>*TS: motivation* | 0: No personalization<br>1: Partially considered<br>2: Fully considered | - Customize the characters and the environment<br>- Ability to modify length or order of the exercises<br>- Different pathways in regard to the user's profile<br>- Personalized messages | - Characteristics of the robots (size, color, form etc.)<br>- Control duration or order of the exercises<br>- Different pathways in regard to the user's profile<br>- Personalized messages | - Customized audio and video<br>- Customized messages<br>- Possibility to arrange the position of the navigation bar | - Customized audio and video<br>- Customized messages<br>- Ability to select model/actor in video |
| 2. Feedback<br><br>*TS: identify the targeted task* | 0: No feedback<br>1: Feedback but is not clearly related to a goal<br>2: Feedback clearly related to a goal | - Specific sound when the answer is correct<br>- Progression bar / timer | - Specific sound when the answer is correct<br>- Progression bar / timer | - Voices feedback when choosing pictures<br>- Sentence construction: automatic adaptation of grammar and syntax | - Opportunity for the user to auto-correct |
| 3. Rewards<br><br>*TS: motivation and learning* | 0: No rewards<br>1: Social reinforcement (applause) or points only.<br>2: Rewards like objects, videos, song | - Social reinforcement (i.e. applause)<br>- Visual rewards (video, pictures,…)<br>- Points | - Social reinforcement (i.e. applause)<br>- Visual rewards (video, pictures, …) | - Social reinforcement (i.e. at the end of a task in VM)<br>- Visual rewards (video, pictures, …) | - Social reinforcement (i.e. at the end of a task in VM)<br>- visual rewards (video, pictures, …) |
| 4.Contextualized learning<br><br>*TS: generalization and social context* | 0: None<br>1: Limited context<br>2: Clear link between game and context | - Real life scenario<br>- Downloadable gaming resources | - Scenario must be designed to allow children to draw connections between themselves and their everyday life | - AAC can include video modelling<br>- Includes Visual scene (VSD)<br>- Add hotspot to VSD by drawing on the screen | - Opportunity to create sequences featuring the user as the model ( video-self modeling)<br>-Ability to create videos featuring user's actual environment. |
| 5. Enhance motivation<br><br>*TS: motivation* | 0: None<br>1: Partially considered<br>2: Fully considered | - Includes a companion or enemy in the game<br>- Contains jokes or humor<br>- Provides encouragement | - Robot must be friendly (i.e.: adapted size and appearance) to engage with the children<br>- P rovides encouragement | - Ability to make jokes or use humor | - Provides encouragement<br>- Motivating factors such as humor or encouragement can be added to videos |

| Features and targeted skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| 6. Manage difficulty<br><br>*TS: accessibility and learning* | 0: No difference between levels<br>1: Changes in difficulty without adapting to the player<br>2: Changes in difficulty in regard to the player (manually or automatically) | - Construct the game to automatically adapt to the level of the player<br>- Allow the user to adapt manually the difficulty<br>- Adapt scaffolding (i.e. provides full support at the beginning of a new task and then diminished it)<br>- Evolving task with increasing difficulty | - Adapt scaffolding (i.e. robot can first initiate the interaction, then just support it) | - Choose between symbolic images, written words, pictograms, or photos to fit with the level of comprehension of the user | Possibility to see each sequence (video prompting) or all tasks at once (video modeling) |
| 7. Increasing accessibility : simplicity to use and autonomy<br><br>*TS: accessibility* | 0: None<br>1: Partially simple (i.e. simple gestures but time consuming)<br>2: Easy to use and easily accessible | - Simple to use for parents or caregivers (avoids time consuming apps)<br>- Minimizes the number of gestures required<br>- Simple gesture needed<br>- Easy to use even for non-technologically advanced people<br>- Not related to a specific device or operating system | - Simple to use for parents or caregivers (avoids time consuming by favoring autonomy of the robots)<br>- Minimizes the number of gestures required<br>- Simple gesture needed<br>- Easy to use even for non-technologically advanced people | - Simple to use for parents or caregivers (avoids time consuming apps)<br>- Minimizes the number of gestures required<br>- Simple gesture needed<br>- Easy to use even for non-technologically advanced people<br>- Not related to a specific device or operating system | - Simple to use for parents or caregivers (avoids time consuming apps)<br>- Minimizes the number of gestures required<br>- Simple gesture needed<br>- Easy to use even for non-technologically advanced people<br>- Not related to a specific device or operating system<br>- Can be watched on devices with built in accessibility features |
| 8. Clarity of the instructions and content<br><br>*TS: accessibility* | 0: None<br>1: Language adapted but not visual<br>2: Visual and language adapted | - Contains a tutorial<br>- Language suitable to developmental age<br>- Visual symbols easily comprehensive<br>- Reminder during tasks | - Language suitable to developmental age<br>- Reminder during task<br>- Robot's actions must be simple and easily understood by the user | - Language suitable to developmental age<br>- Visual symbols easily comprehensive<br>- Using video instead of pictures to help representing actions | - Language suitable to developmental age<br>- Videos are easily understood<br>- Using videos instead of pictures to help understanding actions |

| Features and Targeted skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| 9. Attention capacity<br><br>*TS: Attention and fatigability* | 0: None<br>1: Adaptation of duration OR stimuli to keep the user engaged<br>2: Adaptation of duration AND stimuli to keep the user engaged | - Uses dynamic stimuli to keep the player engaged<br>- Adapts the length of tasks<br>- Diminish transition time between games | - Adapts the length of tasks<br>- Uses dynamic stimuli to keep the player engaged | - Allows real time communication (i.e. with pre-registered sentences)<br>- Relieve working memory by keeping the current sentence visible while looking for the next image | - Adapts the length of the video |
| 10. Clear goals for short and long term<br><br>*TS: accessibility and learning* | 0: None<br>1: Limited number of goals in a session OR clear goals / AAC: limited levels OR thumbnails<br>2: Limited number of goals AND clear goals/AAC: limited level AND thumbnails | - One unique goal per gaming session<br>- Differentiation between the immediate goal (goal of a game) and long-term goal (goal of the story) | - One unique goal per gaming session | - Clear organization: identify category inside a folder (i.e. provide a compilation of images to illustrate a folder instead of one single related image)<br>- Thumbnails are clearer than symbols<br>- Limiting the number of location levels | - One video should be related to one goal |
| 11. Minimalistic graphics and audio: keep the environment pleasant but avoid non-essential elements<br><br>*TS: repetitive behavior and attention* | 0: None<br>1: Minimalistic graphics OR sounds<br>2: Minimalistic graphics AND sounds | - Avoids non-essential animations to prevent repetitive behaviors<br>- Gives the possibility to customize graphics as character's font or background color<br>- Gives the possibility to turn off music or sound effects separately | - Avoids non-essential animations to prevent repetitive behaviors<br>- Has controls for the sounds | - Has controls for the sounds<br>- Gives the possibility to customize graphics as character's font or background color | - Has controls for the sounds<br>- Control over the video (location, actors, props)<br>- Gives the possibility to customize video elements such as graphics, font or background color |
| 12. Human interaction<br><br>*TS: social interaction and motivation* | 0: None<br>1: Exchange with one person<br>2: Multi-users exchange | - Cooperative multiplayer games<br>- Possibility to receive encouragement from family or friends | - Cooperative multiplayer games | - Ability to exchange messages with other people through internet | - Ability for others to create videos |

| Features and Targeted skills (TS) | Rating | Serious games and Apps | Robots | AAC | Video Modeling |
|---|---|---|---|---|---|
| 13. Trustworthy<br><br>*TS: motivation and accessibility* | 0 : None<br>1 : Partially considered<br>2: Fully considered | - Assures safety and cybersecurity if needed<br>- Is robust: avoids bugs and latencies<br>- Clear goals and operation of the device | - Assures safety and cybersecurity if needed<br>- Is robust: avoids bugs and latencies<br>- Clear goals and operation of the device | - Assures safety and cybersecurity if needed<br>- Is robust: avoids bugs and latencies<br>- Clear goals and operation of the device | - Assures safety and cybersecurity if needed<br>- Is robust: avoids bugs and latencies<br>- Clear goals and operation of the device |

**2. Supplementary material related to chapter 4, from:**

**Bettencourt, C., Anzalone, S., Chetouani, M., & Cohen, D., Grossard, C. (2023). Have information and communicative technologies research for neurodevelopmental disorders improved overtime? A systematic meta-review (submitted).**

Tables 2 to 5 summarize the three most cited article from Google Scholar as well as the 3 articles from the highest impact factor journals per domain, respectively robot, ACC, SG and VM. The experimental methodology and main results are described below.

**Table 2. Best papers exploring robots in NDD according to citations or impact factor journals**

| Authors (Years) | Study design | Inclusion criteria (Most cited or best journal) | NDD | Age (y/o) | N total | Duration Intensity | Targeted skill | Type of support | Person delivering the intervention | Main results | Methodology quality | | | Design quality | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Score (max=15 | Strength | Weakness | Score (max=26) | Strength | Weakness |
| **Best papers according to citations** | | | | | | | | | | | | | | | | |
| Robins et al. (2005) | Single case design | 857 times | ASD | 5-10 | 4 | 101 days; each trial lasted as long as the child was OK | Social skils | Robot: ROBOTA & Wizard-of-Oz interface | Investigator in charge of teleoperation | Repeated exposure to an interactive small humanoid robot increased basic social interaction skills in children with autism. | 6 | Longitudinal studies | Difficulty to generalize the results due to small sample size. | 4 | Possibility to teach the robot sequences of actions and vocabulary through machine learning algorithms | Most of the robotics features, including speech processing, motion tracking and learning were not used. |
| Kim al. (2013) | RTC cross over | 481 times | ASD | 4-12 | 24 | 3 sessions; intensity N/A | Social skills | Robot: PLEO & Wizard-of-Oz interface | Three adults not related to the children | Children with autism showed positive social behaviors towards the robot, and the robot was effective in reinforcing social behaviors in the children. | 13 | RCT, large sample of participants in comparison to most robotic interventions. | The study did not include a follow-up assessment to determine the long-term effects of the robot intervention on social behavior in autistic children. | 11 | Appealing characteristics; Possibility to pre program PLEO and instantaneously play any one of 13 custom, pre-recorded, synchronized motor and sound scripts on the robot. | Limited verbal capacities |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Duquette al. (2008) | Single-case vs. 3 controls | 391 times | ASD | 4.4-5.5 | 4 | 22 expositions at a rate of three times per week during 7 weeks; duration of sessions N/A | Social skills | Robot: Tito & Wizard-of-Oz interface | Investigator in charge of teleoperation | Children exposed to the robotic mediator showed reduced repetitive plays with inanimate objects of interest (their favorite toy), and had no repetitive or stereotyped behavior toward the robot. | 10 | N/A | Difficulty to generalize the results due to small sample size. | 8 | Robot's appealing characteristics for interacting with children with ASD | Robot's limited motions capabilities |
| **Best papers according to journal impact factor** | | | | | | | | | | | | | | | | |
| Scassellati al. (2018) | Group study no control | Science Robotics IF2018: 14.034 | ASD | 6-12 | 12 | 1 month; 30-min everyday | Social skills | Autonomus robot: Jibo | None: child/robot interaction | After training, many children invest the robot as a friend and improve their capacity for joint attention, communication and commitment even without the robot. | 12 | Intensity and length of the intervention. Demonstration of directly assessed improvements in social skills. | Unconstrained home environment can lead to greater variations in environmental conditions; no control group; intervention mixed a robot and screen games | 16 | Fully autonomous robot, capable of adapting to the strengths and weaknesses of each child. Adapted to parents for in home interventions. | The interaction between the need for autonomy and the need for adaptation creates additional technical challenges. |
| Kumazaki al. (2018) | RTC | Mol autism IF2018 : 5.869 | ASD | 5-6 | 68 (30 ASD & 38 TD) | 5 min robot interaction | Social skills | Robot: CommU & Wizard-of-Oz interface | Investigator in charge of teleoperation | Participants demonstrated better JA during their interaction with the robot | 14 | Study design | Duration of intervention | 5 | Appealing characteristics; realistic design of the eyes and its mobility facilitate eye contact and joint attention | Lack of different degrees of social complexity |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Huskens al. (2015) | RCT | JADD IF2015: 4.101 | ASD | 13-May | 6 (3 ASD & 3TD) | 5 sessions; 30-min once a week | Social skills | Robot: Nao & TiViPE—a visual programming environment | Investigator in charge of teleoperation | Robot-mediated Lego therapy was not effective in improving collaborative behaviors of children with ASD, although parents social validity reported improvements in their children's collaboratory play. | 10 | Multiple baseline, adequate treatment integrity, interrater agreement scores, post intervention measures, sufficient information provided for replication. | No control group, low intensity of intervention, does not report of long term effect of intervention does noot report on treatment fidelity. | 10 | Robot provides clear instructions, prompts and positive reinforcement, | Limited possibility to adapt to the children's needs and preferences, limited behavioral repertoire (prompts and reinforcement), need for technical assistant to be present to program the robot. |

N/A= not available; JADD= Journal of autism and developmental disorders; Mol Autism= Molecular autism

**Table 3. Best papers exploring AAC in NDD according to citations or impact factor journals**

| Authors (Year) | Study design | Inclusion criteria (Most cited or best journal) | NDD | Age (y/o) | N total | Duration Intensity | Targeted skill | Type of support | Person delivering the intervention | Main results | Methodology quality | | | Design quality | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Score (max=15) | Strength | Weakness | Score (max=26) | Strength | Weakness |
| **Best papers according to citations** | | | | | | | | | | | | | | | | |
| Kasari et al. (2014) | RCT (SMART) | 418 times | ASD | 5-8 | 61 | 24 1-hour sessions during 6 months | Communication | SGD | Therapist | Using SGD as an initial intervention proved to be more impactful than the intervention without. Additionally, implementing an adaptive intervention with the SGD subsequent to the first phase yielded better post-treatment results. | 14 | Rigorous design allowing for the evaluation of multiple interventions and their sequencing; longitudinal; 3-months follow-up. | Only two-thirds of the recruitment target were involved in the study. | 4 | N/A | N/A |
| Reichle & Ward (1985) | Case study | 355 times | ID communication delay | 13 | 1 | 57 trials; intensity N/A | Communication | SGD: *The Sharp communicator* | Speech-language pathologist | The child was able to use the SDG with nonsigners and used sign language with signers accurately after receiving training. | 5 | Multiple baseline design and detailed data collection | Single case | 6 | Direct select encoding reduces the time required to communicate | Device requires prior training |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flores et al. (2012) | Case series | 386 times | ASD, ID | | 5 | 5 weeks, 3 hours/day, 5 days/week | Communication | iPad + SGD *Pick a Word* app | Teacher | Participants benefited from both the app and picture-based communication. Nevertheless, there was no consistent pattern across the participants. | 6 | Data collection and reliability, including treatment integrity, interrater agreement and social validity. | Single case, Only communication behavior was addressed; study setting | 6 | Accessibility of the iPad (cost & availability) | Procedures for activating the iPad and programming the app. |
| **Best papers according to journal impact factor** | | | | | | | | | | | | | | | | |
| Gevarter et al. (2014) | Case study | JADD: IF2014 4.032 | ASD | 3.1-3.6 | 3 | 5–8 weeks 2–3 sessions/ week | Communication | Apple iPad + GoTalk app + Scene and Heard App | Certified special education teacher | Two participants showed more rapid acquisition with the Scene and Heard photographical hotspot than with the GoTalk Widgit symbol button. | 5 | Naturalistic environment, procedural integrity, interrater agreement, three AAC conditions | Small sample size, no control group, | GoTalk: 6 Scene and heard: 9 | GoTalk app: symbol is enlarged and darkened when pressed | GoTalk: Button-based configuration |
| | | | | | | | | | | | | | | | Scene and heard app: photographical hotspot, naturalistic representation | Scene and heard app: Additional stimuli when selecting a symbol led to confusion |
| An et al. (2017) | Group study no control | Mol autism IF2017: 5.872 | ASD, minimally verbal | 3-6 | 10 | 8 sessions of 30-min | Communication | AAC mobile app: Yudee | Teacher | Effective tool for helping minimally verbal children | 8 | Interrater agreement, procedural integrity. | No control group, small sample size, no follow-up, limited to classroom environment, no collect data of parental additional training, some parents. | 18 | Easily customizable based on children's verbal needs, possibility to add more pictures, large repertoire accessible (iOS & Android), visual and auditory feedback | Intensive prior training (8x30 min sessions) |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Xin & Leonard (2015) | Case study multiple-baseline design | JADD: IF2015 IF 4.101 | ASD, ID | 10 | 3 | Two 10-min sessions 2 days/week for 2–3 weeks | Communication | iPad, **SonoFlex** App | Teacher | Using SonoFlex increased students' responses to teachers' questions, social comments. However initiating requests is significantly lower. | 7 | The study used multiple methods to measure changes in communication. | Small sample size, no follow up, and no examination of specitific features of the iPad based intervention. | 12 | Accessibility of the iPad (cost & availibility) | Fixed icon size and all related vocabulary visible on the same screen. |

AAC=Augmented assisted communication; ASD=Autism spectrum disorder; ID=Intellectual disability; JADD= Journal of autism and developmental disorders; Mol Autism= Molecular autism; SMART= Sequential multiple assignment; SGD=Speech generated device; N/A= not available

**Table 4. Best papers exploring serious game in NDD according to citations or impact factor journals**

| Authors (Year) | Study design | Inclusion criteria (Most cited or best journal) | NDD | Age (y/o) | N total | Duration Intensity | Targeted skill | Type of support | Main results | Methodology quality | | | Design quality | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Score (max =15 | Strength | Weakness | Score (max =26) | Strength | Weakness |
| **BEST PAPERS ACCORDING TO CITATIONS** | | | | | | | | | | | | | | | |
| Klingberg et al. (2005) | RCT | 2782 times | ADHD | 7-12 | 53 | Five weeks, 40-min average time | Executive function | SG: CogMed | Treatment group improved working memory compare to control group | 15 | RCT | N/A | 14 | Visual and verbal feedback | No multiplayer, static graphics, no storytelling |
| Klingberg et al. (2002) | Controlled study | 1813 times | ADHD | 7-15 | 14 | 20 min per day, 4±6 days a week, for at least 5 weeks. | Executive function | SG: CogMed | Training significantly improved working memory and visuo spatial skills | 11 | Low-dose version of the same game as placebo | Small sample size | 14 | Visual and verbal feedback | No multiplayer, static graphics, no storytelling |
| Temple et al. (2003) | Controlled study | 1244 times | Dyslexia | 8-12 | 32 (20 dyslexics, 12 TD) | 8 weeks; intensity N/A | Reading skills | SG: Fast For Word Language | Remediation resulted in improved language, reading performance, and increased activation in multiple brain regions during phonological processing | 8 | Using both behavioral measure and fMRI | Small control group | 13 | Auditory processing | N/A |
| Gollan et al. (2006) | RCT | 838 times | ASD | 15-45 | 75 | 10 - 15 weeks; intensity N/A | Social skills | SG: Mind Reading | Participants significantly improved in their ability to recognize complex emotions and mental states from both faces and voices, compared to their performance before the intervention, and relative to the control group | 12 | Large RCT | Lack of participants' description | 12 | Related to social context, adapted to adult | Limited personalisation, 2D static graphics, not very attractive |
| **BEST PAPERS ACCORDING TO JOURNAL IMPACT FACTOR** | | | | | | | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Francesch ini et.al (2013) | Control led study | Current biology IF2013: 9.916 | Dysle xia | 8-12 | 20 | 9 sessions of 80 min per day | Reading skills | Wii video game: Rayman Raving Rabbids | Comparing the effects of an action video game to a nonaction video game training. Action video game improve reading skills in dyslexic children more than in the control group | 10 | Using a placebo in the control group | Lack participants' description small sample size | NA | NA | NA |
| Serret et.al (2014) | Group studyn o control | Mol autismIF 2014: 6.338 | ASD | 6-18 | 33 | Two 1-hour sessions per week over four weeks. | Social skills | SG: JeStimule | Children improved their emotion's recognition skills after training | 12 | Include children with IQ<80 | No control group | 20 | 3D world, possibility to adapt the level of difficulty, the player can make choice and personalized his/her character, clear feedbacks | No multiplayer |
| de Vries et.al (2014) | RCT | JCPP IF2015: 6.284 | ASD IQ >80 | 8-12 | 90 | | Executive function | SG: Braingam e Brian | Control and experimental group improved in working memory and ADHD symptoms. The high attrition rate and the absence of clear effect of the training do not support the use of Braingame Brian with children with ASD | 15 | Large sample of children with a control group using a non adaptative training | N/A | 15 | 3D world with an attractive storyline and beautiful graphics | Limited actions of the player inside the game, no multiplayer |

ASD=Autism spectrum disorder; ID=Intellectual disability; JCPP=Journal of child psychology and psychiatry; Mol Autism= Molecular autism; SG=Serious game

**Table 5. Best papers exploring video modeling in NDD according to citations or impact factor journals**

| Authors (Year) | Study design | Inclusion criteria (Most cited or best journal) | NDD | Age (y/o) | N total | Duration Intensity | Targeted skill | Type of support | Person delivering the intervention | Main results | Methodology quality | | | Design quality | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Score (max=15 | Strength | Weakness | Score (max=26) | Strength | Weakness |
| **Best papers according to citations** | | | | | | | | | | | | | | | | |
| Charlop-Christy et al. (2000) | Case series | 1146 times | ASD | 7-12 | 5 | Duration varied from weeks to months depending on the child, 170 minutes of VM | Social skills | Videotape | Therapists | Comparing video modeling and in vivo training. Video modeling led to faster acquisition of tasks and promote generalization | 6 | Multiple baseline | small and heterogenous sample | 5 | Target behavior are displayed at a slow pace, cost efficiency | No personalisation, no reinforcement, no features to support motivation |
| Ozonoff et al. (1995) | Controlled study | 943 times | ASD (IQ>70) | 12-14 | 9 | 18 weeks | Social skills | Videotape | One primary leader with three additional staff | Increased performance on Theory of Mind Tasks and ratings of social behavior in the training group but not in the control group | 9 | Control group | small sample | 11 | Videotaped of the participants | No model of the targeted behavior, no possibilities to modify the difficulty |
| Charlop & Milstein (1989) | Case series | 733 times | ASD | 3-8 | 3 | Duration varied, biweekly during the VM phase, each video was presented three times at a time; average video length was 45 sec. | Communication | Videotapes | Therapist | Children acquired conversational speech after exposure to the modeling procedure and generalized to all of the probes | 7 | Evaluation at 15 months follow-up after training | The frequency of training was not described and duration depends on the time each child needed to meet the acquisition criterion | 2 | Cost efficiency | No personalisation, no reinforcement, no features to support motivation |

| Best papers according to journal impact factor | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Horn et al. (2008) | Case studies | Int J Behav Consul Ther: IF2008 4.796 | ASD + ID | 17-29 | 3 | Twenty-fvie 15-minute sessions, no more than twice a week | Autonomy | Video tape | Researchers | 2 of the 3 participants learned how to wash clothes with the use of video prompting alone and one needed the least--to-most prompting to performing the skills | 6 | Multiple baseline | Small sample with heterogeneous profile | 6 | Possible to adapt the difficulty by shortening the video | No feedback, no reward inside the video, no features to support motivation |
| Litras et al. (2010) | Case study | Autism res: IF2010: 4.633 | ASD | 3 | 1 | 25 sessions; three times a day; 5 to 3 minute videos | Social skills | Video Modeling: video tape | Participant's parents | The child increased vocal communicative behavior and social engagement/interaction | 6 | Multiple baseline | Small sample | 15 | Videotaped of the participants, cartoon animation to support motivation, clear goal | No feedback, only adapted to this participant |
| Spriggs et al. (2015) | Case studies | JADD IF2015: 4.101 | ASD + ID | 17-19 | 4 | One daily session for 3 months | Autonomy | Video Modeling: My Pictures Talk | Teacher | High school students with autism were able to transition within and between novel activities thanks to video modeling. Students exhibited high rates of generalization to the static visual activity schedules and novel task exemplars after the embedded video model was removed | 7 | Multiple baseline | Small sample | 12 | Possible to personalize and easily modify the VM | No features to support motivation, no feedback |

ID=Intellectual disability; ASD=Autism spectrum disorder; ID=Intellectual disability; JADD= Journal of autism and developmental disorders; Int J Behav Consul Ther=International Journal of Behavioral Consultation and Therapy

**3. Supplementary material related to chapter 5, from:**

**Bettencourt, C., Grossard, C., Segretain, M., Bree, M., Pellerin, H., Anzalone, S., Chetouani, M., & Cohen, D. (2023) Investigating the feasibility and usability of the Wizard of Oz robotic interface R2C3 in a social skills group for autistic children: an exploratory study (submitted)**

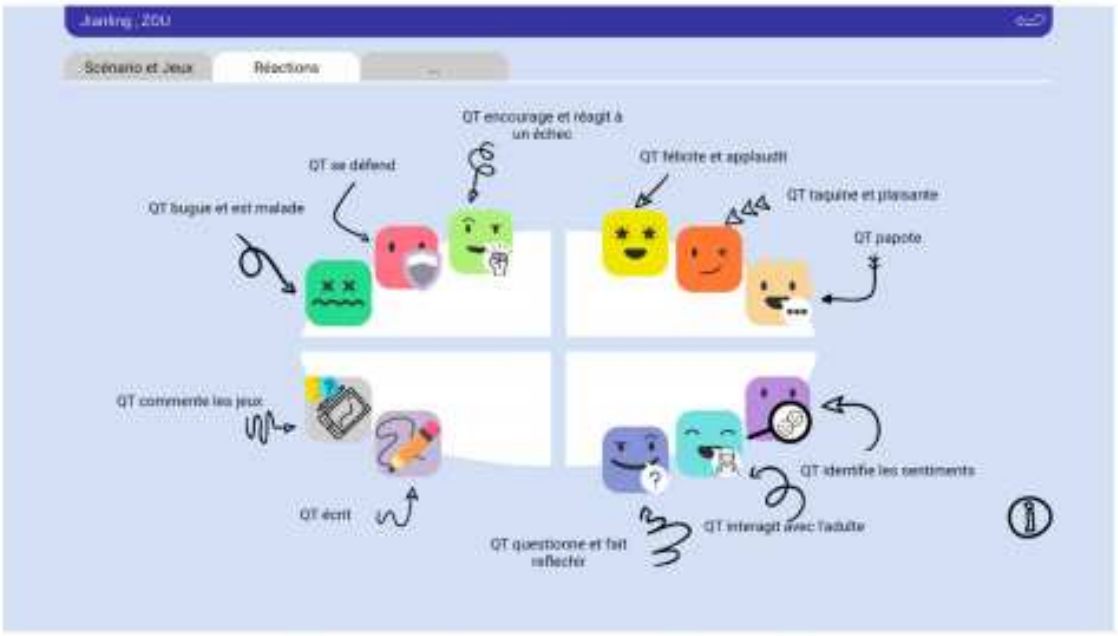
S1 - QT

| | | |
|---|---|---|
|  QT inactive |  QT congratulating |  QT puzzled |
|  QT sad |  QT tired |  QT laughing |

S2: R2C3 INTERFACE (Zou et al., 2023)

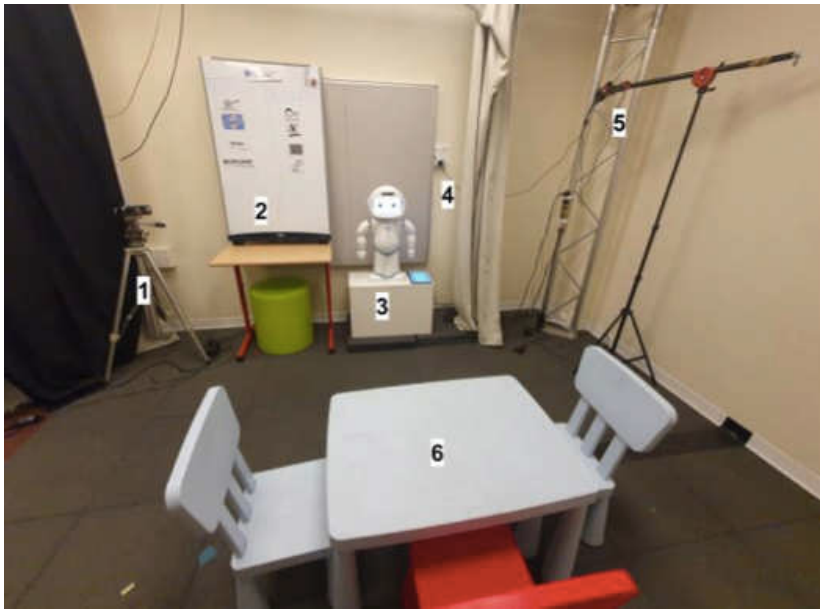

(a) Login page


(b) Control page – scenario and game tab




(c) Control page – reaction tab


(d) Buttons of a menu




**S3: EXPERIMENTAL SET UP**

1: Camera #1

2: Board used to present the activities and take attendance

3: QT robot

4: Camera #2

5: Camera #3

6: Table and chairs

## S4: ACTIVITIES PROPOSED DURING THE 10 SESSIONS

| Sessions | Activities | |
|---|---|---|
| **n°1 : QT inactive** | 1 | - Attendance: each child puts his or her photo and that of the adults present on the table next to the corresponding first name<br><br>- QT says, “Sorry, I’m tired”<br><br>- Explanation of QT’s inactivity: “He is tired today. He does not want to talk, but he is attentive to what we do and looks at us”<br><br>- Child hangs sleeping QT photo on board |
| | 2 | - Gestural imitation: in turn, the children should imitate their neighbour’s gesture and add a new one (too difficult for the children) |
| | 3 | - Identification of basic emotions from the pictogram: joy, anger, fear, sadness<br><br>- Mimic emotions through facial expressions |
| | 4 | - Children choose one of their favourite foods from pictograms on the table in turn<br><br>- Exchange around selected foods: “Do you eat at home?”, “Does anyone else like pizza?” |
| **n°2 : QT active** | 1 | - Attendance: each child puts his or her photo and that of the adults present on the table next to the corresponding first name<br><br>- A child asks if QT is okay today and hangs a picture of him awake |
| | 2 | - Gestural imitation: an adult makes a gesture, and each child imitates it in turn; then the children each try to propose a gesture |
| | 3 | - Identification of emotions and facial expressions<br><br>- Each child picks up an emotion and makes QT guess it |
| | 4 | - From the pictograms, the children take turns choosing their favourite animal and asking QT questions about their preferences |

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|---|---|---|
| **n°3 : QT active** | 1 | - Attendance: each child puts his or her photo and that of the adults present on the table next to the corresponding first name<br><br>- How QT feels today |
| | 2 | - Dance activity: the children take turns proposing movements, and others imitate them |
| | 3 | - From a picture of a situation involving basic emotion, the children describe what is happening and identify the emotion in question<br><br>- QT tries to guess and asks for explanations |
| | 4 | - From the pictograms, the children take turns choosing their favourite sport and asking QT questions about their preferences |
| **n°4 : QT inactive** | 1 | - Attendance: each child puts his or her photo and that of the adults present on the table next to the corresponding first name<br><br>- QT says he's tired today |
| | 2 | - Imitation of facial expressions: the children imitate the facial expressions of others and suggest one to the group |
| | 3 | - Repeat photos from the previous week: the children must again identify the emotions and then reproduce one of the scenes with an adult (difficult activity, especially for younger children) |
| | 4 | - From the pictograms, the children take turns choosing their favourite season and activities they can do at this time of year (difficult activity, too many considerations) |
| **n°5 : QT inactive** | 1 | - Attendance: each child puts his or her photo and that of the adults present on the table next to the corresponding first name<br><br>- QT says he's tired today |
| | 2 | - Song: the children sing with the help of Makaton gestures following the rhythm and intensity proposed by one of the adults |

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|---|---|---|
| | 3 | - From a social picture presenting a specific emotion, the children describe what is happening in the photo and identify the emotion in question. Then, the children act out the situation with the adults |
| | 4 | - The children take turns choosing one of their favourite toys from pictograms |
| **n°6 : QT active** | 1 | - Attendance: each child puts his or her photo and that of the adults present on the table next to the corresponding first name.<br><br>- How QT feels today |
| | 2 | Musical imitation: an adult makes a drum rhythm, and each child imitates it in turn; then the children each try to propose a rhythm |
| | 3 | Symbolic puppet play: the adults offer the children a situation of conflict between two puppets, and the children suggest solutions |
| | 4 | Among the pictograms, the children take turns choosing a food to compose their pizza and ask QT questions about their preferences |
| **n°7 : QT inactive** | 1 | - Attendance: each child puts his or her photo and that of the adults present on the table next to the corresponding first name<br><br>- QT says he's tired today (photo of QT sleeping on board) |
| | 2 | Musical imitation: an adult makes a drum rhythm, and each child imitates it in turn; then the children each try to propose a rhythm |
| | 3 | Symbolic play with puppets: the adults present to the children a situation of conflict between two puppets, and the children suggest solutions |
| | 4 | Among the pictograms, the children take turns choosing ingredients to make their pie; the children share their preferences with the group and question others |
| **n°8 : QT active** | 1 | - Attendance: each child puts his or her photo and that of the adults present on the table next to the corresponding first name<br><br>- How QT feels today |
| | 2 | Musical imitation: an adult makes a drum rhythm, and each child imitates it; the |

| | | |
|---|---|---|
| | | children each try to propose a rhythm to the group |
| | 3 | Symbolic game: the children and adults manipulate puppets and create a story; they propose solutions to social situations |
| | 4 | Among the pictograms, the children take turns choosing a food and placing it in their shopping cart. The children ask questions of each other and ask QT questions about their preferences |
| **n°9 : QT active** | 1 | - Attendance: each child puts his or her photo and that of the adults present on the table next to the corresponding first name<br><br>- How QT feels today |
| | 2 | Musical imitation: an adult makes a drum rhythm, and each child imitates it in turn; then the children each try to propose a rhythm |
| | 3 | Symbolic play: the children and adults play with puppets and create a social story. The children propose solutions to the situations proposed with the help of the adult |
| | 4 | Among the pictograms, the children take turns choosing ingredients to prepare a recipe from a shopping list. The children ask questions to each other and ask QT about his preferences |
| **n°10 : QT inactive** | 1 | - Attendance: each child puts his or her photo and that of the adults present on the table next to the corresponding first name<br><br>- QT says he's tired today |
| | 2 | Musical imitation: an adult makes a drum rhythm, and each child imitates it; the children each try to propose a rhythm to the group |
| | 3 | Symbolic play: the children and adults play with puppets and create a story by proposing solutions to problematic social situations |
| | 4 | Among the pictograms, the children take turns choosing a toy for a friend's birthday from a shopping list and ask questions to their peers |