Analysis of interpersonal communication in a Mixed Reality full-body interaction experience to foster social initiation in children with Autism

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Beauty is in the different.
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Abstract

Autism Spectrum Condition (ASC) is a neurodevelopment condition in which the core deficits lie in social communication and social interaction. Therefore, it is important to help people with ASC to develop socio-communication skills so that they can function efficiently in society. Different therapies have been developed over time, but the emergence of technology and the interest of children with ASC towards the technology has allowed the development of more innovative therapies such as interventions that allow developing face-to-face interactions. These types of interventions focus on the development of active and dynamic systems in which the therapist does not have a direct influence on individuals during the therapy. Therefore, the possibility of ICT, and in particular Full-Body Interaction Mixed Reality System, may be developed to effect social interaction as much as a traditional therapy setting. In addition, physiological changes are related to adaptive behaviors to regulate social interactions. Hence, this thesis is focused on the evaluation of a Mixed Reality face-to-face full-body interaction experience in terms of the interpersonal relationship and communication between ASC and non-ASC children. The experience has been evaluated by a different amount of data sources such as observed overt behaviors, physiological data (HRV & EDA), system log files, and questionnaires allowing us to better understand how users in the experience convey engagement and regulate social interactions. Nevertheless, previous research has only been evaluated the huge amount of data collected from children with autism and all the data of children without autism who participate as playmates in the experience have yet to be evaluated. Therefore, the present study is focused in two main objectives (i) understand the effectiveness of the MR experience in terms of social interaction and social initiation in children without autism and the dyad compared to a typical social intervention strategy, and (ii) understand the relationship between the arousal activity and the overt social interaction behaviors in the MR environment compared to the typical social intervention. Results show how the full-body mixed reality system can be a good mediator in socialization, specifically in fostering social initiations between a child without autism and a child with autism and being a new dynamic tool for interventions with children with autism. The positive results obtained are of great interest to promote further research on the system and to develop a new
version that may be easier to carry out in school settings. Also, the active system can help children without autism to better integrate children with autism into society.

Keywords: Autism Spectrum Condition; Interpersonal Communication; Full-body Interaction Intervention; Social Initiation
1. Introduction

Autism Spectrum Condition (ASC) is a neurodevelopment condition in which the core deficits lie in social communication and social interaction. Therefore, it is important to help people with ASC to develop socio-communication skills so that they can function efficiently in society. Different therapies have been developed over time, but the emergence of technology and the interest of children with ASC towards the technology has allowed the development of more innovative therapies that use, for example, virtual environments. These types of interventions focus on the development of active and dynamic systems in which the therapist does not have a direct influence on individuals during the therapy. The development of these interventions is of great importance since the development of a person within a society is based on their interactions and exchange of information with the other people who are part of that society. The study of social interaction between people focuses on interpersonal communication, which is used to understand how individuals use verbal and nonverbal language to achieve instrumental and communicative goals, such as informing, persuading, and providing emotional support to others. One of the research categories found within interpersonal communication is human adjustment and adaption of verbal and nonverbal communication during face-to-face interaction. Face-to-face interaction is determined by the mutual influence of the direct physical presence of individuals with their body language. This type of interaction is one of the key elements of a social system, playing an important role in individual socialization and the experience acquired throughout the person’s lifetime.

In the following sections, we will discuss in more detail the characteristics of ASC, the affinity that people with autism have towards Information and Communication Technologies (ICT), the basis of full-body interaction interventions and the different methodologies that can be used to assess interpersonal communication in therapies followed by children with autism. The background for the development of this study and the main objectives will be explained at the end of this section.
1.1. Autism Spectrum Condition

ASC is a neurodevelopment condition affecting communication and behavior and presented in the early development period. According to the DSM-5, a guide created by the American Psychiatric Association, people who present ASC can exhibit different types of deficits, especially concerning social communication and social interaction. Another main characteristic of ASC is to show restricted, repetitive patterns of behavior, interests or activities. These core deficits prevent ASC people to function properly in a society that is highly focused on social and communication interactions.

1.1.1. Diagnosis

Diagnosis of ASC can prove difficult since specialists must look at the child’s behavior and development. Autism presents itself during the first development stages, and an experienced professional is usually able to make a reliable diagnosis of autism by age 2. At this specific moment parents can decide to diagnose their children for ASC. This involves two steps: developmental screening and a comprehensive diagnostic evaluation. The field of psychiatry has a large variety of developmental screening tools for autism. Common screening tools include the Social Communication Questionnaire and the Child Behavior Checklist, which are implemented under a structured interview. Once the screening for autism is done, it is possible to use different tools for the comprehensive diagnostic evaluation. The diagnostic evaluation may be done based on an interview such as the Autism Diagnostic Interview (ADI-R) for adults or based on an observational assessment such as the Autism Diagnostic Observational Schedule (ADOS), considered as the gold standard of observational assessment. The structured interview and the direct observation may be accompanied with an intelligence quotient (IQ) measurement. The IQ can be measured using the Wechsler Intelligence Scale for Children (WISC) or other Developmental Scale tools, such as Vineland.

The revised version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) changes how ASC is classified and diagnosed. Prior to this new version, people could be diagnosed with one of several distinct conditions such as autistic disorder, Asperger’s’ syndrome or pervasive developmental disorder not otherwise
specified (PDD-NOS). The current version, DSM-5, does not make a distinction between these different conditions and combines them into a single diagnosis called ASC. In the following sections, we will refer to the ASC as “autism”. In addition, the ASC may comprise different subgroups depending on the level of functioning indexed by overall IQ.12

1.1.2. Social and communication difficulties

The core deficits of people with autism lie in social communication and social interaction. When we talk about social interaction, we have to understand it as a reciprocal process in which children effectively initiate and respond to social stimuli presented by their peers in diverse social settings and situations13. Nevertheless, people with autism present deficits in social-emotional reciprocity, which can lead to failure to initiate or respond to social interactions, integrate verbal and non-verbal communication behaviors and deficits in developing, maintaining and understanding relationships. Despite this, high-functioning children with autism are more likely to initiate or respond in peer interaction compared with low-functioning children with autism.14 However, high-functioning children with autism show poor quality and low frequency of their social behaviors compared with children without autism.15 When we talk about poor quality behaviors, we refer to behaviors such as ritualistic behaviors and maintaining close proximity (i.e. behaviors with minimal social enactment), rather than performing prosocial behaviors such as sharing feelings and experiences (i.e. high-level social behaviors).14 In addition, research with children with high-functioning autism has found that they can maintain social interactions once these have been initiated, that is, their ability to respond to a partner's interaction is better than their ability to initiate such interactions.16 In contrast, peer interactions in the non-ASC population are multi personal in nature and become articulated during the preschool years.17

The poor quality and low frequency of social behaviors achieved by high-functioning children with autism show the importance of developing interventions and tools to foster interpersonal communication skills. This is since conversational and play skills are the structure of efficient social interaction with peers,18 which are in turn
fundamental for the development of comprehensive cognitive, linguistic, and social skills in children.16

1.1.3. Current therapies

Many behavioral treatments and interventions are available to improve the quality of life of people with ASC. As we have seen in previous sections, people with autism can vary depending on the level and types of their symptoms and deficits. Therefore, interventions and treatments are adjusted to address the person’s specific needs. Different therapies are usually conducted, such as Applied Behavior Analysis (ABA), Early Start Denver Model (ESDM), DIR/Floortime, Occupational Therapy (OT), Relationship Development Intervention (RDI), Speech Therapy and Pivotal Response Treatment (PRT).

The ABA intervention aims to reinforce desired behaviors and decrease behaviors that are harmful or affect learning. The strategy to achieve this specific goal is through the usage of positive reinforcement. This type of therapy has been seen to improve communication abilities, social behaviors, play skills, as well as looking and imitating, and perspective-taking. 7,19

ESDM is a specific therapy for children with autism between 12-48 months, based on both the ABA methodology and the teaching practices. Results from different research have shown improvements in learning, language abilities and adaptive behaviour and reductions in autistic symptoms.20

DIR/Floortime is a relationship-based therapy for children with autism in which parents play and interact with the child at their physical level, i.e., the parent and the child play on the floor. The goal of this intervention is to help children expand their “circles of communication” through child-led interactions. Therapists teach parents to direct their children to more complex interactions. 21
OT therapy aims to improve skills that are used every day such as play skills, learning strategies and self-care. 22

RDI is a family-based intervention that focuses on building social and emotional skills, i.e., strengthening the building blocks of social connections. In most of the cases, parents are trained as the primary therapists.23

The main goal of Speech Therapy is to help people with autism to communicate in both useful and functional ways. This intervention may help to addresses challenges with verbal, non-verbal and social communication.24

PRT is a play-based therapy initiated by the child based on the ABA methodology. The main goals of this approach are to develop communication and language skills, increase positive social behaviors and provide relief from disruptive self-simulatory behaviors. The main characteristic of PRT is that the therapist focuses on pivotal areas such as motivation, response to multiple cues, self-management and the initiation of social interactions instead of one specific behavior.25

1.2. Autism and ICT

Research on how to engage children with autism has shown promising results on the affinity that children with autism have towards the ICT.2 The affinity of children with autism to patterns and logic could drive interest from them to computational knowledge due to its systematic nature. Many researchers have utilized ICT to create interventions and learning experiences for children with ASC to promote engagement and dynamic interventions.7,26

It is possible to distinguish a large variety of ICT-based therapies using different types of technology such as interactive environments (computer-based, touch screens and virtual reality), virtual environments and robotics.7,26
Interactive Environments

The uses of collaborative interactive environments, such as virtual environments (VE), have important relevance in this field. The interactive environments allow the researchers to control the input stimuli and the monitoring of the behavior of the children. Therefore, the interactive environment provides information about important factors for the children’s progress. The main goal of interactive computer games is the improvement of the collaboration between multiple users.

It is possible to use different types of interactive technologies such as computers, touch screens and virtual reality experiences depending on how researchers wish to develop digital-based interventions. Computer-based interventions focus on user-computer relationships. The results of computer-based therapies have revealed the following: (a) increase in focused attention; (b) increase in overall attention span; (c) increase in sitting behavior; (d) increase in fine motor skills; (e) increase in generalization skills (from computer to related non-computer activities); (f) decrease in agitation; (g) decrease in self-stimulatory behaviors; and (h) decrease in perseverative responses. However, with advances in technology, most recent research projects use a touch screen for input feedback instead of a common mouse device.

Virtual Environments

Virtual environments allow researchers to recreate social situations in which the user can participate as a player in 3D scenarios safely and realistically. In addition, the virtual environments are stable and predictable environments which allow reducing the anxiety that people with autism may present during real social interactions. Moreover, children with learning disabilities prefer programs that include animation, sounds and voices.

Recent studies have shown how virtual environments are used and interpreted satisfactorily by people with autism. The use of this technology allows people with autism to learn social skills and promotes higher levels of enjoyment in educational settings. In addition, the VE allows real-time cause-effect behaviors to be carried out.
and this may contribute to a greater motivation of the child during the performance of the intervention.26

Robotic
Research that uses robots in the treatment of children with autism has been growing in recent years. The robot can acquire the role of practice or reinforcement during the intervention.26 The imitation, joint attention and interactive engagement are key issues in the development of assistive robotics.26 Therefore, interactive robotics systems are used to assess responses of children to robot behaviors. Results have shown positive responses of children with autism for practising imitation30 and joint attention.31,32 In addition, recent literature has shown how robots can generate a high degree of motivation and engagement in children with autism, including those who are unlikely and unwilling to interact socially with human educators or therapists.26

1.3. Full-Body Interaction Interventions
Advances in technology allow the production of interventions that, despite being based on technology, do not require strict user-computer-and-mouse interaction, focus instead on full-body interactions. Full-body interactions can be understood as “using the movements and the actions performed in the physical space by the body of the user as mediators of the interactive experience” allowing for more intuitive and natural interaction with the environment.34 Besides, full-body interaction technologies allow carrying out face-to-face collaboration and to assist learning. Researchers using full-body interaction techniques have shown positive results in fostering social behaviors.35,36

The use of the body as a mediator for interactive experiences is based on the theories of Embodied Cognition. Embodied Cognition theories modify the traditional Cartesian concept that sees the body and the mind as two separate entities: the mind being the centre of all cognitive activity and the body as a support to it.7 Embodied Cognition theory holds that the functionality of the mind must be understood in unison with the body.37 Therefore, the cognition of each individual is influenced and connected with
their body dynamics and their social context. At the same time, this is influenced by all prior individual experiences and perceptions. The learning process is therefore produced by social activities among humans as constructors of knowledge (situated learning), where meaning is created through collaborative interaction with others and the world around us.

In the Autism Spectrum Condition section, we have seen how people with autism can show both motor and communication deficits. Through the use of full-body interaction interventions, it is possible to foster verbal and non-verbal communication. The latter has been shown to aid thinking about and understanding others. Conventional user-computer interaction interventions do not usually encourage such non-verbal communication.

Full-body interaction interventions have the advantage of being able to foster social and communicative interactions between peers since collocating multiple users in the same physical space allows for a fluidity of awareness of other’s actions, creating a natural dynamic of collaboration and allowing for implicit and immediate understanding between users and ecological validity as it is the most similar situation to real-life social interaction. That is, children with autism can practise their social skills by interacting naturally with other children which are not possible in user-computer interactions.

In the Autism and ICT section, we have seen that virtual environments are suitable for interventions on children with autism, which may be further enhanced by using full-body interactions, allowing users to move freely within the environment. Full-body virtual environments place the body at the centre of attention since the user controls systems with body movements, incorporating the use of gestures and non-verbal language, which are key to interpersonal communication. Also, large scale interactive full-body environment allows a physical exploration of the medium and face-to-face interactions between users.

During recent years some researchers have implemented embodied interaction for motor movement therapy, play therapy, and socialization via collocated interaction.
1.4. Evaluation methods for Autism

Research with children with high-functioning autism has found that their ability to respond to a partner's interaction is better than their ability to initiate social interactions. Therefore, different interventions try to foster social initiation behaviors in children with autism. In the following sections, we will explore different methods to assess social behaviors during social interventions.

1.4.1. Video Coding evaluation

To assess the effectiveness of social interventions for children with autism, tools that are based on observational schemes are often used. Video coding is one of the most common technique to assess the changes in social behaviors that occur during the intervention. The typical methods for video coding are based on making recordings of the sessions to later be able to encode observational behaviors.

Mc Conachie et al. and Anagnostou et al. have analyzed the different outcome measures that exist for autism-specific interventions yet could not find one tool that was deemed completely satisfactory. Bolte et al. have found that there is no consensus among researchers regarding the tools that should be used to perform the analyzes, that is, there is no one common scale to analyze interventions for children with autism. This is because researchers modify and create social observation scales to fit their interventions.

A scale called Social Interaction Observation System (SIOS) is described in Bauminger et al. (2002). The scale is used to code behaviors during playground recess sessions before and after the intervention and used in parallel with other assessment tools such as problem-solving measures, an emotional inventory, and teacher reports to detect changes in emotional understanding and social skills. The scheme presented in Bauminger’s study is based on the Behavior Coding Scheme for children presented in Hauck et al. This scheme is used to evaluate the occurrence of social initiations in naturalistic settings on children with learning disabilities and autism.
McMahon et al. have used an adaptation of Bauminger’s coding system to evaluate the social behavior of children and adolescents with ASC weekly over 19 weeks of a social skills training program. The researchers code children’s verbal speech as initiating, responding, or other (e.g., self-talk) and interactions are coded as dyadic interactions were with a peer or leader and whether small group interactions were with a group of peers only, a group of peer(s) and leader(s)small group interactions, or time spent by self.

To appropriately observe the naturalistic peer-engagement and to obtain a comprehensive assessment of social-communication in high-functioning children with ASC, Bauminger et al. (2019) have described a new scale called Autism Peer Interaction Observation Scale (APIOS). APIOS comprises a 3-hour observational procedure to assess social-communication abilities and difficulties of preschoolers in spontaneous peer interactions during various activities in and out of preschool.

A scale called Autism Behavior Coding System (ABCS) has been created to address the need for sensitive measures to capture core autism-related behaviors focusing on the social communication domain as well as on repetitive behaviors. Initially, the ABCS scheme was developed to assess the effectiveness of the development of an early intervention called “Frühintervention bei Autistischen Störungen” (FIAS). The FIAS is a play-based, intensive early intervention approach for children with autism aged up to 5 years. “ABCS is an event record-based coding system and provides a detailed, continuous protocol of the presence or absence of a particular behavior and its total duration (in seconds) or frequency within a given observation period”.

To measure autism-specific development and capture change in social communication behaviors over time in minimally verbal children, Kitzerow et al. have developed a new coding scheme called Brief Observation of Social Communication Change (BOSCC). Items on the BOSCC are developed based on ADOS-2 codes but the coding scheme is expanded to capture more nuanced changes in social behaviors over time. The scheme consists of a total number of 16 items in which social communication abilities and restricted and repetitive behaviors are captured.
To capture the playground engagement states, Locke et al. have described the Playground Observation of Peer Engagement (POPE) scheme which is a timed-interval behavior-coding system. Playground engagement states are expressed as the percentage of intervals children spend in solitary play and jointly engaged with others (i.e. turn-taking in a game or reciprocal engagement in conversations or joint activities).

Based on a developmental psychology approach, observation schemes have also been created for use in social and collaborative play environments for children without autism.

In the Play Observation Scale (POS) the authors divide the behaviors into Play or No-Play, then assign qualifiers such as social or cognitive play. They then define items within categories such as functional play and exploration. The Outdoor Play Observation Scheme (OPOS) is an evaluation scheme that can be used for head-up games for children or those with generalized outdoor games. In this evaluation scheme, researchers distinguish between point events and states, depending on the continuity and duration of the behavior. Using this scheme, observers watch videos of the play activity and make structured observations of the children’s physical activity, focus, social interaction, and general issues. Although the scheme focuses on the activity of the child, it does not have items that take into account the abilities of children with autism.

1.4.2. Physiological evaluation

All communication, verbal or non-verbal, is not possible without the direct intervention and interaction of the multiple anatomical and physiological systems. Interpersonal communication and the environment surrounding these communicative behaviors have a considerable role in influencing, and being influenced by, physiological processes. Studies by Beaty et al. (1998) have shown how communication apprehension is related to the behavioral inhibition system, if it is high there is an overactive of the inhibition system while if it is low there is an underactive. Floyd’s works have also shown how
the amount of affection received and given to others serves as a physiological stress reduction function. Also, people who have high communication skills, such as being able to express their emotions, maybe less stressed or anxious as a result, than people who do not have such skills. Furthermore, emotions can play a considerable role in the potential dysregulation of physiological stress responses. The autonomic nervous system responds differently to different types of emotions such as fear or love.

Research that includes physiological measures in autism have shown how a person may express an emotional external state completely different from its emotional internal state. The emotional state of a person could be defined, although not perfectly represented, as valence (pleasant or unpleasant or positive versus negative) and arousal (activated versus deactivated or excited versus calm), constituting a key aspect of communication. Physiological arousal is regulated by the sympathetic and the parasympathetic activity, two subdivisions of the autonomic nervous system (ANS). When the sympathetic activity increases (sympathetic arousal) the heart rate, blood pressure and sweating are elevated as a result. Therefore, electrodermal activity (EDA) and heart rate variability (HRV) are good indicators of arousal, which increase and decrease respectively, in the face of sympathetic nervous system activation.

EDA changes based on superficial skin conductance, therefore, providing a sensitive and convenient measure to assess sympathetic arousal changes associated with emotion, cognition and attention. One of the main challenges of people with autism is their difficulty in communicating socially and emotionally due to discomfort when looking at faces and making eye contact. These discomforts are associated with increased ANS activation and hyper-arousal of associated brain regions. In Hirstein et al. the researchers have found how the EDA of a person with autism may have a high oscillation similar to physical exertion, but without any visible signs of sweating, heavy breathing or outward stress.

HRV is an emergent property of interdependent regulatory systems that operate on different time scales to help people to adapt to environmental and psychological challenges, making it possible to index cardiac vagal tone. Cardiac vagal tone
represents the contribution of the parasympathetic nervous system to cardiac regulation in connection to cognitive, emotional, social, and health self-regulation. Research has found that participants with ASC evidenced reduced parasympathetic cardiac control, which correlated with social behavior and a person with autism can show a high resting heart rate (120 beats per minute (b.p.m.) or more, instead of the usual 60–80 b.p.m.) while seeming externally calm.

1.4.3. Multimodal evaluation

Human face-to-face communication is a multimodal process in which there is a combination of different signals such as vocal (verbal language), visual (non-verbal language) or physiological (emotional internal state) to convey engagement and regulate social interactions. Advances in technology have allowed the development of new tools to observe these different signals during social interactions (affective and social cues), which include the use of videos to observe behaviors (emotional external state) and sensors to acquire physiological data (emotional internal state). Taking these advances into account, the need for mechanisms that allow making multimodal evaluations may also become apparent.

In the field of human-computer interaction (HCI) and human-robot interaction (HRI), the use of various social and affective cues to facilitate and evaluate the user engagement cues or interaction events are used. The researchers do this by detecting the presence of a set of engagement cues or interaction events or using supervised classifiers trained with social, physiological, or task-based interaction features. Unlike classifiers for a single modality, the multimodal procedure allows improving the estimation of the target outcome (e.g., user engagement).

Recent research has found how machine learning (ML) techniques, and in particular deep learning, promote the use of technologies to perceive (semi)automated affective states and engagement of children during therapies for children with autism. In the study of Rudovic et al., the authors have demonstrated the possibility of using ML techniques to allow the robot's perception of affection and engagement in children.
undergoing autism therapy. It also shows how autonomic physiology acquired by EDA, HR and body temperature can reflect visible external changes in anticipation.

The data acquired can help therapists and researchers see idiosyncratic behavior patterns of children with autism interacting with other children and to observe changes in these patterns during multiple therapy sessions.

1.5. Research context and objectives

The interpersonal communication, and especially face-to-face communication, has an important role in individual socialization and the experience acquired throughout the person’s lifetime. Nevertheless, high-functioning children with autism show deficits in developing quality social interactions. To improve the quality of life of people with autism, a wide variety of interventions have been developed, especially with the advancement of technology. It is important to be able to carry out interventions that allow developing face-to-face interactions.

A novelty Mixed Reality face-to-face full-body interaction experience called Lands of Fog (LOF) to foster social initiation behaviours in children with autism7,36 has been developed in the Full-Body Interaction Lab at Pompeu Fabra University. The experience has therefore been evaluated by different data sources such as observed overt behaviors, physiological data (HRV & EDA), system log files, and questionnaires. Nevertheless, only the data of children with autism have been evaluated and the data of children without autism who participated as playmates in the experience have yet to be evaluated. The analysis of the data of the non-ASC children is important since the interpersonal communication in social interaction cannot be analysed by considering just acting individuals in isolation, but we must instead consider individual behaviors within the context of peer interaction (figure 1).73
The analysis of all the data (children with autism and children without autism) will allow us to better understand the effectiveness of the Mixed Reality system based on the interpersonal relationship and communication between ASC and non-ASC children. Previous results show a relative equivalence between the MR system (LOF, dynamic system) and the typical social intervention (LEGO, passive system) on ASC children alone. To better understand the whole effectiveness of the MR system it is needed to see what happens to non-ASC children and the dyad. In particular, to understand the whole MR experience we will analyse the following:

(1) Compare the social interactions (initiations, responses and externalizations) and the social initiations of non-ASC children with respect ASC children in two different conditions: LEGO and LOF.

(2) Compare the total number of social interactions (initiations, responses and externalizations) and social initiations attitudes observed of the dyad (sum of the data of the non-ASC and ASC children) in two different conditions: LEGO and LOF

The analysis of multimodal data (overt behaviors and physiological data) will allow us to understand the relationship between the arousal activity and the overt social interactions behaviors of the non-ASC children coded in the MR environment (LOF) compared to a typical social intervention (LEGO) based on the physiological data sources.
2. Methods

The methodology section will focus the first subsection on the explanation of the hypothesis of the present study, the following two subsections on the context and content about which the present study is based. Subsequently, the design and set-up in which the experiments were carried out and the procedure for the data gathering (overt behaviors, physiological data, anxiety, and individual and collaborative actions) will be explained.

2.1. Hypothesis

As we have seen in the Research Context and Objectives section, the present study focuses on two main objectives: (1) understand the effectiveness of the MR experience compared to a typical social intervention strategy (LEGO), and (2) understand the relationship between the arousal activity (internal active state) and the overt social interactions behaviors in the MR environment compared to the typical social intervention (LEGO). From the objectives, it is hypothesized that there will be (1) as many social interactions (initiations, responses and externalizations) and social initiations of non-ASC children to ASC children in the MR environment (LOF) compared to the typical social intervention (LEGO) coded from video recordings of the play sessions, (2) as many social interactions and social initiations of the dyad (sum of the non-ASC children and ASC children data) in the MR environment (LOF) compared to the typical social intervention (LEGO) coded from video recordings of the play sessions, and (3) possible to classify the social initiations of the non-ASC children during the MR system and the typical social intervention conditions through their changes on the arousal activation monitored through physiological measurements.

2.2. Context

The present project is based on the results of previous studies. A novelty Mixed Reality face-to-face full-body interaction experience called Lands of Fog (LOF) to foster social initiation behaviours in children with autism\textsuperscript{7,36} has been developed in the Full-Body Interaction Lab (FubIntLab) at Pompeu Fabra University. The results have shown
positive effects and great potential in the use of this system in fostering social and collaborative behaviors in children with autism while playing exploratorily with a child without autism. As discussed in the objectives, in the present study we want to see if the results are equally positive when analyzing the data of the play partner of the child with autism, i.e., the analysis of the data of the children without autism. Therefore, the same methodology used in previous studies was followed.

The experiment follows a protocol that uses objective and standardized data collection. As a control condition, elements of LEGO play therapy were used, which is a common tool in social skills training for autism. And as an experimental condition, the MR system developed in the FubIntLab was used. Therefore, the MR system was compared with LEGO play therapy.

2.3. Content

The LOF system is a mixed reality full-body interactive environment that offers a response and feedback on the progress of the players. In contrast, the LEGO condition is a passive system; since the elements of the game, that is, the pieces, give neither response nor feedback to the children actions. Therefore, when the dyad is playing to LOF, the system responds in a way that promotes a feeling of positive reinforcement to the players. In a conventional intervention, in which ICT is not used, the therapist promotes positive reinforcement while is managing the session and guiding the children. Thus, LOF assists therapists in mediating interactions between players and provides players with a controlled context to implement their social behaviors.

2.4. Population

In the study, the experiments were developed with a pair of players: a child with high-functioning autism and a child without autism. A total of 72 subjects (36 children with autism and 36 children without autism) between the ages of 8-12 years (N = 12 female, N = 60 male) participated.
Children with autism were recruited through the Sant Joan de Déu Hospital in Barcelona. For the study, the children with high functioning autism who had a diagnosis for autism determined by the scale of Observation for the Diagnosis of Autism (ADOS) module 3, designed for young people with verbal fluency, with a minimum severity diagnose of 4,11 were recruited.

Children without autism were recruited through flyers distributed among schools of Barcelona and through dissemination on social media. The selection criteria for children without autism was that they did not have a diagnosis for autism or some other condition.

Additionally, both ASC and non-ASC children had to score a minimum IQ of 70 as determined by the Wechsler Intelligence Scale for Children74.

2.5. Experimental design and set-up

For the development of this project, the subjects were exposed to both conditions in a single experimental session: LOF system (experimental condition) and LEGO play therapy (control condition). Therefore, the experimental sessions were divided into two parts: the LOF condition and the LEGO condition, which each part lasting 15 minutes. Each pair of children played each of the conditions once. The assignment of the order of the conditions was carried out randomly, through an online statistical web program, to counterbalance the effect of the order of the tasks. (see Appendix A for a scheme of the experimental design) Additionally, at the beginning of the experiment, the researcher-in-command determined if the session would follow a goal-oriented or open-ended version (see sections 2.5.1. The Mixed Reality System: Lands of Fog and 2.5.2. Non-ICT play activity: LEGO for more details).

The procedures performed during the sessions followed the 1964 Helsinki declaration and the ethics committee of the hospital granted subsequent amendments and ethical approval for conducting the sessions. Informed consents were obtained from the legal representatives of all the children who participated in the study. In addition, at least one
legal representative must accompany the child and be present during the entire experimental session. The psychologist who guides the children during the session and 1-3 researchers were also present during the session.

At the start of the session, the psychologist informed and introduced the children to the setup of the experiment and the researchers. Before starting the session, the researchers and the psychologist of the study were in charge of requesting the signed consents from the children's legal representatives and if they did not have it, they were provided with a new one. Without the signed consent, the session could not go on.

Once the consents were obtained, the psychologist began the session in a similar way to what would be done in a therapy session. This was done with visual support called “Jumby is Calm”75 of the type used in social skills therapy, relying on visual cues as a tool to anticipate the results of the new situation.76 Later, the children were introduced to the materials that they were going to be using during the experiment. The networks with LED lights that they were going to use to interact with the MR system were showed. While the psychologist explained what was going to be done and showed the materials to the children, the researchers took advantage of the fact that the children were distracted to attach the electrodes on them (see the procedure in the Physiology: HRV and EDA section), first to the kid without autism and then to the kid with autism. The sensors were integrated into a wearable (see the details in the Physiology: HRV and EDA section) that made it more fun and kid-friendly. Then, in a work of coordination and collaboration between the researchers and the psychologist, the researcher asked the psychologist about the children's language preference and selected it on the tablets which were later used for the questionnaires. After attaching the electrodes and knowing each child's language preference, the psychologist performed a relaxation activity with the children to control any anxiety produced by the wearable or the laboratory setting. The children then performed a minute of baseline. Before starting any of the experimental conditions, the children answered a short questionnaire (see section 2.6.3. Anxiety) followed by a minute of baseline. Also, before starting the LOF condition, the psychologist of the study showed to the children a short video to explain how they could use the interactive net with the virtual environment. After playing 15 minutes of LOF or
LEGO, the children answered another questionnaire about what they had played (see section 2.6.3. Anxiety) followed by a minute of baseline. After this first part of the session, the children made a break of 5 minutes. Subsequently, the process was repeated with the second of the conditions. After the whole process was complete, the researcher detached the electrodes of the kids. See Appendix B for a scheme of the steps followed during an experimental session.

In the following sections, the set-up of the LOF system and the typical LEGO play therapy conditions are explained in more detail.

2.5.1. The Mixed Reality system: Lands of Fog

The MR full-body interactive system was designed specifically for children with autism as space for them to practice social initiations with a child without autism as a partner. It is an installation based on a virtual environment that fosters a natural attitude of exploration and discovery through hidden objects and virtual surprises.

Installation
The system is projected from two Full HD projectors with blended images. To interact with the virtual elements of the environment the children holds a butterfly net fitted with LED lights (i.e. a physical object) that are tracked by a camera tracking system to get the position of the object in the playing field plane. The physical object acts as a guide element allowing the child to focus his/her attention on the environment.

Additionally, the system encourages creative exploration between the child with autism and their non-autistic peer through a variety of sound and visual elements. On the other hand, it uses subtle strategies to get players closer, such as manipulating props and making creatures evolve.
Game theme

The game is based on a fantasy world. The world to discover is covered with a dense virtual fog that does not allow the children to see what is under it. To see what is hidden, players should move to clear the fog with the help of their nets. Under the fog, players can visualize and capture certain insects. The insects captured change to the colour of the children’s net, evolve and become different creatures when the two children are very close to each other. The main objective of the game is to find two key pieces that have been to open a door that is in the middle of the environment. For a further description of the game design, refer to Mora-Guiard et al.36

Goal-oriented or open-ended

If the session is goal-oriented, the psychologist explains to the dyad beforehand that they have a total of 15 minutes to find the parts of a lost key that will allow them to open a door that is in the centre of the environment (explaining the goal of the game). On the other hand, if the session is open-ended the psychologist indicates to the dyad that they have to explore the scenario together and discover what lies behind this world.

2.5.2. Non-ICT play activity: LEGO game

LEGO play therapy was created and based on Daniel Legoff’s therapy. Legoff used LEGO brick sets to mediate communication between groups of children with autism, obtaining positive results in improving the acquisition of social skills.77 This strategy was adopted to create the shared LEGO play experience between the child with autism and the child without autism.
Installation

To play the LEGO game, a hexagon-shaped table was built to allow the fluid movement of children around it. The centre of the table is the space used to build different constructions. In each of the vertices, a container with LEGO pieces was placed. In total there were six containers with the pieces separated by colours. Figure 3 shows the structure of the table.

Game theme

The LEGO control condition was, in turn, structured into two subparts: (1) the search for the hidden "pirates" and (2) the construction of the boat. During the first part, the therapist indicates to the pair of children they should found the “pirates” (LEGO figures) hidden among the containers on the table (with one figure per container). During the search, the children could see images of the hidden “pirates”. In total, they needed to find six different "pirates". Once they found them, the therapist indicated them to proceed with the construction of the boat with the LEGO blocks and to place the "pirates" found on it.

Goal-oriented or open-ended

If the session is goal-oriented, the psychologist shows to the children at the beginning of the game an image as an example for the construction of the boat and tells them that they have to build it together. On the other hand, if the session is open-ended the psychologist indicates to the dyad that they have to build a boat, without showing any picture as an example or guidance to carry out the task.
2.6. Data gathering

As we have seen in the previous sections, the objective of the present project is to analyze and compare the LOF system to a typical LEGO social intervention strategy. For this, the analysis of the data is based on four data sources gathered while children play both conditions: (1) video coding of the overt behaviors during the video recorded play sessions, (2) physiological data (EDA and HRV), (3) an anxiety standard questionnaire and (4) log files of our system showing the events triggered and the real-time decisions took.

2.6.1. Overt behaviors

To evaluate effectively the outcomes of the face-to-face full-body interaction experience, i.e. to evaluate the overt behaviors of the dyad, all sessions were recorded through two GoPro cameras positioned on opposite sides of the interactive space, which provided a wide-angle of view of the entire interaction space. Additionally, to obtain quality audios in the recorded videos, two quality microphones were connected (one in each camera) since the conversations are crucial to understand and encode social behaviors.

Recordings of the control and experimental condition, lasting 15 minutes, were cut by the lead researcher, Batuhan Sayis, in 5-minute sections. Subsequently, the first and last 5 minutes of each condition were coded to assess social behaviors (social initiations, responses and externalizations). To assess the overt behaviors, the research group designed a new video coding scheme due to the lack of standard schemes for evaluating settings where the system plays a role in encouraging socialization towards or between the children with autism and without autism. The scheme created is based on the evaluation of Bauminger of social-emotional understanding in children with ASC to code the overt behaviors of the children, being subsequently adapted with the help of the Hospital Sant Joan de Déu and the psychologist of the project.

The BORIS video coding software was used to codify the social behaviors, which allowed to simultaneously watch the two videos of the opposite sides of the interactive
space. After the sessions were recorded, the recorded conversations were transcribed by people with native Spanish and Catalan languages into a written document. The written document was used by the researchers during the video coding of social behaviors.

For the video codification, the full stepwise method represented in a flowchart designed by the research group was followed. The coding scheme is based on the fact that each social behavior is either an initiation or a response. However, in the case that the behavior was not strictly directed towards the play partner it was coded as "Externalization". The social behaviors towards the video game characters or other people who were not their play partner present in the laboratory setting were not coded. Before determining whether the interaction was directed or not, it had to be previously identified whether it was a verbal or non-verbal interaction. In the case of being verbal, only those interactions that were recorded in the video transcription could be encoded. If more than 80% of the words were not understood, the social interaction was marked as “conversation”. However, if more than 80% of the words were understood and the social interaction was directed to his/her playmate (marking it as initiation or response), it would be marked as high-level (positive or negative social interaction) or low-level interaction. In Appendix C the flowchart used for the video coding is shown, which specifies also the different categories of high-level and low-level interactions.

Essentially, each event was coded at the specific time that it occurred. Each event should be distinguished between a singular event (“point event”) with a duration of less than 5 seconds or a prolonged event (“state event”) with a duration of more than 5 seconds. Additionally, the events had to be separated by a minimum of 5 seconds between them. If several interactions occurred during the 5 second time interval, the event with the highest level of interaction was coded. An exception to this was when a response included an initiation. In these cases, both events were marked even if they were separated by less than 5 seconds.

For a further description of the video coding scheme, refer to Sayis, B. et al.78
Training
For the present study, training before the video coding of the social behaviors of all the sessions was carried out. First, the psychologist of the project and the researcher-in-command explained what were the main behaviors to code and the details of their subcategories. Subsequently, three videos were coded in which the child with autism was the focus of the codification. These videos were indicated by the psychologist or the researcher of the project. After coding, the results obtained were compared with those obtained by the psychologist or the researcher of the project and any doubts that might have arisen were resolved.

Possible extension of the scheme
Possible extensions that could be applied to the scheme developed by the research group are analyzed in this section.

When children with autism or without autism perform social initiations with their peers in both conditions, they may sometimes not receive a response from their peer. In this case, as a consequence, the child can decrease the number of social initiations during the game or promote the child's solitary play. Therefore, it would be interesting to add a subcategory to indicate if the social initiation was successful or unsuccessful as used in POPE.51 If it is a successful initiation, the child who performs the social initiation (verbal or non-verbal) receive a response (verbal or non-verbal) from his/her peer. In contrast, if it is an unsuccessful initiation, the child who performs the social initiation interaction (verbal or nonverbal) does not get a response (verbal or nonverbal) from his/her peer. The same mechanism should be applied in the response category. In this case, it should be specified whether the response has been made (“Done”) or not (“Not-done”). The results would allow us to analyze the possibility of adding new emerging elements in the system to promote a greater number of social initiations and to analyze in greater depth the internal states of children.

With what has been said, and although it is not so related to social communication per se, it would be interesting to have recorded the moments in which the child was playing
alone, interactively or not playing. This classification is based on the one used in ABCS. An independent category would be added to the scheme that would allow us to evaluate the functional game. The outcomes would allow us to see the potential of the MR system as an active system by seeing more interactive play among children. The results could also be analyzed to see possible existing relationships with social communications.

About the categories of the scheme, a new category in high-level positive social interaction could be added to differentiate the explanations (“Explanations”) that children made about the game during the development of it. This new category differs from “Share / Show interest” since child's attention was not focused on a particular object or event in the game and from “Sharing experiences” since it did not give information about an external experience. In addition, the name of the category "Social communication" and its explanation can lead to confusion. Therefore, it could be named as "Shared action" since it is a communication that promotes an action that must be carried out by the dyad.

2.6.2. Physiology: ECG and EDA

To obtain the physiological data, the biosignalplux multimodal platform developed by the PLUX company was used. The research group designed and developed a wearable specifically for children with autism, to obtain reliable physiological data (robust to artefact movements) in full-body interactive environments. Additionally, the wearable was designed to make the experience fun and child-friendly by being hidden in a wearable in the shape of a superhero’s cape. The design and the wireless transmitter on the device allow the free movement of children, having their hands free of sensors and cables and sending the data to a computer, which allows them to interact more naturally with the environment. It used gelled self-adhesive disposable Ag/AgCl electrodes, as adhesive pads are another way to help reduce the impact of electrode movement on signal integrity. The methodology previously designed by the research group was applied. The researcher group decided to attach the EDA electrodes on the shoulder of the children to get a reliable signal which is least affected by movement artefacts. On the other hand, to obtain reliable data of the ECG signal, the electrodes may be placed in
places relatively devoid of the underlying muscle. Therefore, to avoid movement artefacts, the electrodes may be placed on the torso. Following the research group methodology, two of the three lead ECG electrodes were placed on the upper region of the chest and the ground electrode was placed on the spine section of the neck (figure 4). Furthermore, the position of the accelerometer (ACC) in the wearable was aligned with the shoulder EDA electrodes so that the movement artefacts on the EDA signal could be related to ACC data.

In the experiment, the data acquisition started with the help of Biosignalplux Synchronization (SYNC) accessory. After attaching the electrodes on the children, the two devices were synchronized with the synchronization kit.

**Figure 4. Position of ECG and EDA electrodes**

**ECG processing and feature extraction**

The HRV indicates the parasympathetic nervous system index, which is of great interest since greater parasympathetic activity of the vagal tone is associated with better social functioning. In the study, HRV was computed from the raw ECG signal obtained through the electrodes of the wearable; the signal was extracted as a text file and imported it into Kubios. The samples were manually inspected by Batuhan Sayis for possible artefacts. The processing of the signal features was performed in a time window of 30 seconds with a series of R-R intervals after the start of each social initiation. The R-R interval refers to the time between two R peaks of a traditional ECG signal. All features were extracted in the time-domain, the frequency-domain and the nonlinear indices that the spectrum of Kubios includes.
**EDA processing and feature extraction**

The EDA signal is made up of the superposition of two signals: the tonic level of skin conductance (SCL), representing the baseline signal, and the superimposed phasic increases in conductance. The phasic components reflect a unitary skin response (SCR). In turn, the responses are given by the activity of the eccrine sweat glands in response to external stimuli. In the present study, we want to analyze children's responses to external stimuli during experimental activities. Therefore, the phasic components of the EDA signal were evaluated.

The decomposition of both components of the EDA signal was done through a software package for MATLAB called Ledalab 3.4.9. The Automatic EDA Artifacts Identification library EDA Explorer was used to identify possible artefacts in the samples and, afterwards, they were corrected by interpolation. The movements of the body did not generate strong artefacts, so the features of the signal could be correctly extracted. Subsequently, the deconvoluted signal was analyzed by the default peak detection algorithm. To detect significant peaks, the local maximum must have a difference greater than 0.01 μS compared to the previous or must follow a local minimum. The phasic features were calculated within a response window (rw) up to 4s of duration after the start of the social initiation. The EDA features were calculated using the default z-scale values option. All the features included in the Ledalab’s analysis spectrum were extracted.

**Training and experiment**

Before carrying out the experiments, the researcher-in-command, Batuhan Sayis, held a practical session to show how the biosignalplux multimodal platform should be used before, during and after the experimental session. Also showing how the electrodes should be placed correctly on children during the experimental session. The process to be followed in the experiment consisted of: (1) checking that the synchronization kit was working correctly before the start of the session, (2) during the session, placing the electrodes on the children as shown in figure 4, and (3) using the biosignalplux multimodal platform, checking that the signal acquired through the electrodes was good,
otherwise, changing the position of the electrodes for a good acquisition, (4) synchronizing the pair of devices before starting the experiment, (5) being aware that the electrodes were in the correct position during the whole course of the session and (6), at the end of the session, detaching the electrodes carefully and finishing with the acquisition of the data through the platform.

2.6.3. Anxiety

To obtain data on changes in anxiety, questionnaires were carried out through a tablet before and after each experimental condition. Standardized questionnaires called STAIC (State-Trait Anxiety Inventory for Children) were used. The questions were read aloud to each child, by the psychologist of the project to the child with autism and by the researcher to the child without autism, while the tablet screen was shown. Therefore, the child could read the question and mark the answer. The pre-condition questionnaire was shorter and with closed questions, while the post-condition questionnaire contained closed and open questions. Additionally, parents completed the CBCL (Child Behavior Checklist) prior to the experiments.

2.6.4. Individual and collaborative actions

The LOF system also recorded data related to player activity through internal logs. Individual or collaborative actions were registered with timestamps when these were activated while children were playing. Individual actions imply that the player participated in the game without the help of his/her partner and collective actions are those that activate or endgame mechanisms when the two children were in contact with the object of interaction in the virtual space. Additionally, the movement of the two players through the virtual space was also tracked and recorded.
3. Results

After the data was gathered, results were extracted to determine the efficacy of the MR full-body system in fostering social interactions and social initiation related activity between children without autism (non-ASC) and children with autism (ASC) and to understand the relationship between the arousal activity and the overt social interactions behaviors. The main interest was the differences in social initiations and social interactions (social initiations, social responses and externalizations) of the non-ASC children towards the ASC children between the control condition (LEGO) and the experimental condition (LOF). This section contains information for the analysis of video coding recorded overt behaviors, physiological data and questionnaires. The first subsection will focus first on the pre-processing of the data and second on the explanation of the descriptive statistics used to explore the overt behaviors, the physiological data and the questionnaires data, and the following subsection will focus on the results obtained.

3.1. Data analysis

In this study, the two groups (one starting with LEGO condition and the other starting with LOF condition) were exposed to the first condition (independent variable) and the dependent variable was measured (overt behaviors, physiological data and questionnaires data). Afterwards, the two groups were exposed to the second condition (independent variable) and the same dependent variable was measured. (see the methodology’s scheme in Appendix A).

3.1.1. Pre-processing of the data

Before starting with the analysis of the data, different pre-processing of the data was needed. The pre-processing of the data depended on the type of the dependent variable: overt behaviors, physiological data (EDA) and the data of the questionnaires.
Overt behaviors

First of all, the amount of different overt behaviors (social initiations, social responses, externalizations and social interactions) were extracted from the video coding overt behaviors data. The software Python was used to program a code to extract the total number of each feature in each trial. A final excel with all the data was obtained.

Secondly, the data was prepared, and invalid data was discarded before starting the in-depth analysis. The inclusion-exclusion criteria followed to exclude data was that each trial had to have data from both the first 5 and last 5 minutes in each condition (i.e., LOF-First5, LOF-Last5, LEGO-First5, LEGO-Last5). Four trials were discarded to not fulfil the inclusion criteria.

Finally, to measure the efficacy of the MR full-body system in the dyad was necessary to compute the data of the dyad. It was computed as a sum of the data obtained in this study (data of the children without autism) and the data obtained in previous studies (data of the children with autism).

Physiological data

For the analysis of the arousal activity, the EDA data was used. The EDA was assessed by choosing the features, which represents the phasic activity most accurately such as CDA SCR (average phasic driver within response window (rw)), CDA ISCR (area of the phasic driver within rw) and CDA AmpSum (sum of SCR-amplitudes of significant SCRs within rw) together with the GlobalMean (mean of the skin conductance value within response window). The mean of each feature for each overt behavior (social initiation, social response and externalization) and when the characters merged in LOF was calculated in each trial. Data were excluded if one of the two data was missing when paired with social initiations.

Questionnaires

Depending on the dependent variable analyzed (anxiety level or how well children know their partner), different data was used and extracted from the questionnaires.
On the one hand, the STAIC questions were used to compute the anxiety level. To analyze the anxiety level was needed to convert the values obtained in the 20 items to the corresponding values and then sum the different scores to get the final anxiety state score for each trial. The inclusion-exclusion criteria followed to exclude data was that all the items had to be answered.

On the other hand, the question “How well do you know your partner?” was used to know differences between before and after playing at each condition. An excel was computed with the scores of the answers of each child without autism. The inclusion-exclusion criteria followed to exclude data was that four answers by each child were needed (pre-LEGO, post-LEGO, pre-LOF, post-LOF). Eight trials were discarded to not fulfil the inclusion criteria.

3.1.2. Analysis

The participants were the same individuals tested under two different conditions (LOF and LEGO, categorical independent variable) on the same dependent variable (overt behaviors: social initiations, social responses, externalizations and social interactions; physiological data: ECG and EDA; questionnaires: anxiety level and knowledge of the partner). In all these cases, a paired-sample t-test was used to determine whether the mean difference between paired observations was statistically significantly different from zero, i.e., was used to search for significance (p < .05). Moreover, boxplots were created to check whether the data had outliers in the differences between the two conditions. In addition, a Shapiro-Wilk test was run to check if the distribution of the differences in each dependent variable between the two conditions were normally distributed. A Wilcoxon signed-rank test was used if the data was nonparametric and a sign test was used if both the data was nonparametric and the distribution of differences was not symmetrically shaped.
3.2. Results of the study

3.2.1. Overt behaviors

The first and second hypotheses of this study were to determine the efficacy of the MR full-body system in terms of social initiations and social interactions (dependent variables) of non-ASC children towards the ASC children and of the dyad (sum of the non-ASC children and ASC children data) when it is compared to the typical social intervention (LEGO) coded from video recordings of the play sessions. Regardless the main focuses of this thesis were the social initiations and social interactions, analysis for social responses and externalizations were also run. In addition, analysis of the data of the ASC children was also run to compare them with the results obtained from the data of the non-ASC children. (see Appendix D for an accurate explanation of the results obtained for the ASC children data)

Table 1 and 3 show the total number of outliers found in each overt behaviour (see Appendix E to see the boxplots of the differences of each overt behavior). Different outliers were detected in social responses (data of the non-ASC children) and externalizations (data of both the non-ASC children and dyad) data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. Inspection of their values did not reveal them to be extreme and they were kept in the analysis since the results were not altered. In addition, regardless of the social responses data of the non-ASC children, the difference scores for the LOF and LEGO conditions were normally distributed, as assessed by Shapiro-Wilk's test. See table 1 and 3 to see a summary of the Shapiro-Wilk’s test values.

See tables 1, 2 and 3 for a summary of all the results obtained in each overt behavior. And see table 4 and Appendix F for a summary and graphs, respectively, of the means and standard deviations for the overt behaviors data (non-ASC children, ASC children and the dyad).
Social initiations

Non-ASC children
There were more social initiations from non-ASC children towards ASC children when playing in LOF condition ($M = 11.500$ initiations, $SD = 12.529$) as opposed to the LEGO condition ($M = 10.940$ initiations, $SD = 8.944$). In contrast, there were fewer social initiations from ASC children towards non-ASC children when playing in LOF condition ($M = 8.340$ initiations, $SD = 7.897$) as opposed to the LEGO condition ($M = 9.160$ initiations, $SD = 8.313$). In addition, the LOF condition elicited a not statistically significant increase in social initiations by the non-ASC children compared to LEGO condition, $M = 0.563$ initiations, 95% CI [-3.063, 4.188], $t(31) = .316$, $p > .05$. (see Table 1 and 4)

Dyad
There were fewer social initiations when playing in LOF condition ($M = 19.840$ initiations, $SD = 17.060$) as opposed to the LEGO condition ($M = 20.090$ initiations, $SD = 13.489$). In addition, the LOF condition elicited a not statistically significant decrease in social initiations compared to LEGO condition, $M = -0.250$ initiations, 95% CI [-5.740, 5.240], $t(31) = -0.093$, $p > .05$. (see Table 3 and 4)

Social responses

Non-ASC children
A Wilcoxon signed-rank test determined that there was a statistically significant decrease in social responses ($Mdn = -1.500$ social responses) when subjects played in the LOF condition ($Mdn = 2.000$ social responses) compared to the LEGO condition ($Mdn = 4.000$ social responses), $z =-2.822$, $p = .005$. (see Table 2 and 4) In contrast, there was not a significant decrease in social responses from the ASC children towards the non-ASC children between both conditions.

Dyad
There were fewer social responses when playing in LOF condition ($M = 9.340$ responses, $SD = 8.797$) as opposed to the LEGO condition ($M = 13.220$ responses, $SD = 10.364$). In addition, the LOF condition elicited a statistically significant decrease in
social responses compared to LEGO condition, $M = -3.875$ responses, 95% CI [-6.842, -0.908], $t(31) = -2.664$, $p < .05$. (see Table 3 and 4)

**Externalizations**

*Non-ASC children*

There were more externalizations when playing in LOF condition ($M = 3.690$ externalizations, $SD = 4.020$) as opposed to the LEGO condition ($M = 2.340$ externalizations, $SD = 2.209$). In addition, the LOF condition elicited a not statistically significant increase in externalizations compared to LEGO condition, $M = 1.344$ externalizations, 95% CI [-0.029, 2.716], $t(31) = .55$, $p > .05$. (see Table 1 and 4) Same results were obtained for ASC children.

*Dyad*

There were more externalizations when playing in LOF condition ($M = 9.660$ externalizations, $SD = 7.673$) as opposed to the LEGO condition ($M = 7.440$ externalizations, $SD = 6.790$). In addition, the LOF condition elicited a not statistically significant increase in externalizations compared to LEGO condition, $M = 2.219$ externalizations, 95% CI [-0.690, 5.127], $t(31) = 1.556$, $p > .05$. (see Table 3)

**Social interactions**

*Non-ASC children*

There were fewer social interactions when playing in LOF condition ($M = 18.880$ interactions, $SD = 18.043$) as opposed to the LEGO condition ($M = 19.720$ interactions, $SD = 14.550$). In addition, the LOF condition elicited a not statistically significant decrease in social interactions compared to LEGO condition, $M = -0.844$ interactions, 95% CI [-5.985, 4.298], $t(31) = .740$, $p > .05$. (see Table 1 and 4) Same results were obtained for ASC children.

*Dyad*

There were fewer social interactions when playing in LOF condition ($M = 38.880$ interactions, $SD = 28.684$) as opposed to the LEGO condition ($M = 40.75$ interactions, $SD = 24.187$). In addition, the LOF condition elicited a not statistically
significant decrease in social interactions compared to LEGO condition, $M = -1.875$ interactions, 95% CI [-10.803, 7.053], $t(31) = -0.428$, $p > .05$. (see Table 3 and 4)

Table 1. Summary of the results for overt behaviors of the non-ASC children’s data (parametric data)

<table>
<thead>
<tr>
<th>Overt Behaviors:</th>
<th>Paired differences (Total amount in LOF – Total amount in LEGO)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Outliers</td>
<td>Shapiro-Wilk’s test</td>
</tr>
<tr>
<td>Social initiations</td>
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<td>.589</td>
</tr>
<tr>
<td>Social responses</td>
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<td>.000</td>
</tr>
<tr>
<td>Externalizations</td>
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<td>.120</td>
</tr>
<tr>
<td>Social interactions</td>
<td>0</td>
<td>.602</td>
</tr>
</tbody>
</table>

Table 2. Summary of the results for overt behaviors of the non-ASC children’s data (non-parametric data)

<table>
<thead>
<tr>
<th>Overt Behaviors:</th>
<th>Paired differences (Total amount in LOF – Total amount in LEGO)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shapiro-Wilk’s test</td>
<td>Median</td>
</tr>
<tr>
<td>Social responses</td>
<td>.000</td>
<td>-1.500</td>
</tr>
</tbody>
</table>

Table 3. Summary of the results for overt behaviors of the dyad’s data (parametric data)

<table>
<thead>
<tr>
<th>Overt Behaviors:</th>
<th>Paired differences (Total amount in LOF – Total amount in LEGO)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Number of Outliers</td>
<td>Shapiro-Wilk’s test</td>
</tr>
<tr>
<td>Social initiations</td>
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<td>.957</td>
</tr>
<tr>
<td>Social responses</td>
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<td>.593</td>
</tr>
<tr>
<td>Externalizations</td>
<td>1</td>
<td>.539</td>
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<tr>
<td>Social interactions</td>
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<td>.811</td>
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### Table 4. Summary of the means and standard deviations for each condition

<table>
<thead>
<tr>
<th>Overt Behaviors:</th>
<th>Mean ± Standard Deviation</th>
<th>Non-ASC children</th>
<th>ASC children</th>
<th>Dyad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overt Behaviors:</td>
<td></td>
<td>LOF</td>
<td>LEGO</td>
<td>LOF</td>
</tr>
</tbody>
</table>

#### 3.2.2. Physiological data

The third hypothesis was that would be possible to classify the social initiations related activity of the non-ASC children during the MR system and the typical session intervention conditions through their changes on the arousal activation monitored through psychophysiological measurements. The analysis focused on the arousal changes between social initiations and the other events such as social responses and externalizations during LOF and LEGO conditions and when the characters merged in LOF condition.

Extreme outliers, which was more than 3 box-lengths from the edge of the box in a boxplot were removed in the analysis. When we searched for a difference between social initiations and social responses, externalizations and merging characters in terms of arousal activation, we did not find any significant difference between the selected EDA’s features (Global Mean, CDA SCR, CDA ISCR and CDA AmpSum) in either event. See table 6 in Appendix G for a summary of the total number of outliers found in each event and the results obtained.
3.2.3. Questionnaires

Both the question of how well children know their partner and the anxiety level questions were analyzed although were not directly related to the main hypothesis. These data could be used to determine better the efficacy of the MR full-body system in terms of creating a context to foster social interactions of the non-ASC children towards the ASC children when it is compared to the typical social intervention (LEGO) scored from the answers of the questionnaires.

**Knowing the partner**

Only one outlier was detected in LEGO condition that was more than 1.5 box-lengths from the edge of the box in a boxplot. Inspection of its value did not reveal him to be extreme and it was kept in the analysis since the results were not altered. The difference scores for the pre-condition and post-condition were normally distributed, as assessed by Shapiro-Wilk’s test ($p = .117$ in LEGO and $p = .103$ in LOF). There were higher scores in the answer of knowing the partner after playing in LEGO condition ($M = .771$ score, $SD = .230$) as opposed to before playing in LEGO condition ($M = .558$ score, $SD = .292$). In addition, the test revealed that the children without autism felt like they knew their partner significantly more after the LEGO control condition than before the experiment, $M = .213$ score, 95% CI [.120, .307], $t(27) = 4.669, p < .001$. Moreover, there were higher scores after playing in LOF condition ($M = .764$ score, $SD = .240$) as opposed to before playing in LOF condition ($M = .593$ score, $SD = .330$). As in LEGO condition, the test revealed that the children without autism felt like they knew their partner significantly more after the LOF condition than before the experiment, $M = .171$ score, 95% CI [.088, .254], $t(27) = 4.243, p < .001$. See table 5 for a summary of the results obtained of the paired differences of knowing the partner.
Table 5. Summary of the paired differences of knowing the partner results

<table>
<thead>
<tr>
<th>Condition</th>
<th>Shapiro-Wilk’s test</th>
<th>Mean ± Standard Deviation</th>
<th>95% CI Lower</th>
<th>95% CI Upper</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEGO</td>
<td>.117</td>
<td>.213 ± .242</td>
<td>.120</td>
<td>.307</td>
<td>4.669</td>
<td>27</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>LOF</td>
<td>.103</td>
<td>.171 ± .213</td>
<td>.088</td>
<td>.254</td>
<td>4.243</td>
<td>37</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

**Anxiety level**

There was one outlier in the state anxiety data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. The outlier with a difference score of -7 was removed. The difference scores for the LOF and LEGO conditions were normally distributed, as assessed by Shapiro-Wilk’s test ($p = .120$). There was fewer state anxiety level after playing in LOF condition ($M = 39.235\ SA, SD = 1.776$) as opposed to the LEGO condition ($M = 39.853\ SA, SD = 1.708$). In addition, the LOF condition elicited a not statistically (but almost statistically) significant decrease in state anxiety compared to LEGO condition, $M = -0.618\ SA$, 95% CI [$-1.237, 0.002$], $t(33) = -2.028, p = .051$. 
4. Discussion and Conclusions

The possibility of ICT, and in particular Full-Body Interaction Mixed Reality System, may be developed to effect social interaction as much as a traditional therapy setting. Therefore, the general purpose of this study was to better understand the effectiveness of a full-body MR in terms of the interpersonal relationship and communication between non-ASC children and ASC children. The focus for the analysis of this thesis was children without autism, who participated as playmates of children with autism.

Fostering social initiations and social interactions

The video coding of social behaviors revealed that the MR system is as good as the typical social intervention to promote social interactions (social initiations, social responses and externalizations together) and social initiations related activity by the child without autism towards the child with autism, by the dyad and by the child with autism towards the child without autism. Results show no significant differences between the MR full-body system, LOF, and the typical social intervention, LEGO, in terms of social initiations and social interactions by the child without autism towards the child with autism and by the dyad. In addition, in contrast to the results found of the overt behaviors by children with autism towards children without autism, children without autism performed more initiations, although no significantly, in Lands of Fog than in LEGO. Also, the mean number of initiations in both conditions produced by the child without autism towards the child with autism were greater than the mean number of initiations produced by the child with autism towards the child without autism. More correlational statistical analysis could be done to see if a greater number of initiations may promote the development of a more affective context of the play, making the play partner feel more relaxed and produce a greater number of interactions as a consequence. On the other hand, a significant difference was found in the mean number of responses produced by children without autism in the LOF condition compared to the LEGO condition. The mean number of responses produced by children without autism was significantly lower in the LOF condition and the same result was found in the social responses produced by the dyad. Additional statistical analysis could be done to see if not getting answers from your partner of play may lead to a decrease in the number of social interactions and social initiations. Moreover, the mean number of externalizations...
was almost significant greater in LOF compared to LEGO by the child without autism and not significantly greater by the dyad. In the case of the children with autism, we found also no significant greater mean number of externalizations. Additional statistical analysis could be run to see if an externalization produced by a child without autism may have led to a social initiation by the child with autism, and vice versa.

Additional results were found from the data gathered by the questionnaires although were not directly related to the main hypotheses. The anxiety level questions and the question of how well children know their partner could be used to determine better the efficacy of the MR full-body system in terms of creating a context to foster social interactions and social initiations related activity of the children without autism towards the children with autism when it is compared to the typical social intervention. One conclusion is that the use of game elements seems to have been successful in making children engage more with the peer, as results show a significant increase in children’s level of knowing each other. In addition, social interactions are fostered in a context where there is no stress or anxiety. The questionnaires collecting data on state anxiety level revealed that children without autism had almost a significantly lower state of anxiety after playing LOF compared to LEGO. Further analysis could be run to see if a lower state anxiety level contributed to produce a higher mean number of social initiations related activity.

In conclusion, we can see how both media are at the same level and serve as a positive context to foster social behaviors. In addition, the MR full-body system, Lands of Fog, is an ecologically valid environment for face-to-face social interaction in real life. These positive results are of great interest to promote further research on the face-to-face full-body interaction between a child with autism and a child without autism since the social interaction is determined by the mutual influence of both children and because individual behaviors must be considered within the context of peer interaction. Also, further research on the system and how to develop a new version that may be easier to carry out in school settings could be consider.
**Changes in arousal activity**

Part of this study was to investigate the psychophysiological arousal activity in the full-body MR experience in terms of HRV and EDA during social interactions from children without autism towards children with autism. We analyzed the possibility that social initiation behaviors of children without autism could relate to the arousal activity. The values of the EDA's features for social initiations were compared with the values of the EDA's features for the other events (responses, externalizations and when the characters merged in LOF) and no significant differences were found. One explanation might be the need to use other types of multimodal analysis such as Machine Learning techniques, which would possibly allow classifying and predicting social interactions through the use of all the physiological data (HRV and EDA). The use of multimodal analysis techniques may allow the creation of classification models that in turn would allow differentiating how users react differently in terms of arousal activity in each condition.

To sum up, the results of this study allow us to better understand how a full-body MR experience can be a good mediator in socialization, specifically in fostering social initiations between a child without autism and a child with autism and being a new dynamic tool for interventions with children with autism. In addition, we help children without autism to better integrate children with autism into society.

**Limitations and future work**

**Population**

For the development of the experiment, a dyad consisting of a child with autism and a child without autism was selected. The selection criteria for children without autism was that they did not have a diagnosis for autism or some other condition. However, the underlying introversion/extroversion personality trait was not considered in the inclusion criteria. A child with an extraverted personality, unlike an introverted personality, tends to be a more social and communicative person and with a greater tendency for group activities. The personality trait may be taken into account in further studies as an inclusion-exclusion criterion for children without autism.
Transcription methodology
The transcription of the videos of the play sessions was done by people who listened to the audios of the videos and transcribed them into a document. Sometimes the audios were not entirely clear due to external noise. This limitation may sometimes lead to the loss of information since the interactions between the children were not understandable or the child who was interacting was not clear. In future research, a software that allows automatic transcription of the audio may be used complementarily. On the other hand, to avoid losing information due to external noise, the wearable developed to obtain physiological data may be used to add a microphone.

Mixed Reality System: Lands of Fog
The Lands of Fog system was created to foster collaboration and socialization between a peer. The system encourages collaboration and proximity between children through different strategies. An example is the convolution of the characters when the two networks are close to each other. However, this event can be very sensitive and encourage the convolution of the characters very often, which can create a demotivating feeling. Further studies may study the possibility to promote more feedback from the system to children and decrease the sensitivity of those actions that may confuse them.

On the other hand, the system requires a large space so it cannot be easily carried into school environments or used in smaller spaces. In future research, a new version of the game and the system may be made allowing a more rewarding interaction between users and could be installed in smaller spaces.

Changes in arousal activity
One of the limitations was the analysis of the physiological data. For the analysis, only the EDA data was used to see if it would possible to relate changes in arousal activity and social initiations. In future research, both the HRV data and EDA data may be used to study possible relationships between arousal activity and social initiations through multimodal analysis such as Machine Learning.
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8. Appendices

8.1. Appendix A

Figure 5. Scheme for the experimental design
8.2. Appendix B

Figure 6. Scheme for steps followed during an experimental session
8.3. Appendix C

Figure 7. Flowchart used for the video coding
8.4. Appendix D

Results of the overt behaviors of the ASC children data.

Social initiations
There were no outliers in the social initiations data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. The difference scores for the LOF and LEGO conditions were normally distributed, as assessed by Shapiro-Wilk's test \( (p = .447) \). There were fewer social initiations when playing in LOF condition \( (M = 8.340 \text{ initiations}, SD = 7.897) \) as opposed to the LEGO condition \( (M = 9.160 \text{ initiations}, SD = 8.313) \). In addition, the LOF condition elicited a not statistically significant decrease in social initiations compared to LEGO condition, \( M = -0.812 \text{ initiations}, 95\% \text{ CI } [-3.715, 2.090], t(31) = -.571, p > .05 \).

Social responses
One outlier was detected that was more than 1.5 box-lengths from the edge of the box in a boxplot. Inspection of its value did not reveal him to be extreme and it was kept in the analysis since the results were not altered. The difference scores for the LOF and LEGO conditions were normally distributed, as assessed by Shapiro-Wilk's test \( (p = .920) \). There were fewer social responses when playing in LOF condition \( (M = 5.660 \text{ social responses}, SD = 5.807) \) as opposed to the LEGO condition \( (M = 6.780 \text{ social responses}, SD = 4.963) \). In addition, the LOF condition elicited a not statistically significant decrease in social responses compared to LEGO condition, \( M = -1.125 \text{ responses}, 95\% \text{ CI } [-3.001, 0.751], t(31) = -1.223, p > .05 \).

Externalizations
Three outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. Inspection of its values did not reveal them to be extreme and it were kept in the analysis. The difference scores for the LOF and LEGO conditions were not normally distributed, as assessed by Shapiro-Wilk's test \( (p = .035) \). There were more externalizations when playing in LOF condition \( (M = 5.870 \text{ externalizations}, SD = 6.024) \) as opposed to the LEGO condition \( (M = 5.090 \text{ externalizations}, SD = 6.770) \). In addition, the LOF condition elicited a not statistically significant increase in
externalizations compared to LEGO condition, $M = .875$ externalizations, 95% CI [-1.319, 3.069], $t(31) = .81, p > .05$.

**Social interactions**

There were no outliers in the social interactions (social initiations, social responses, and externalizations together) data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. The difference scores for the LOF and LEGO conditions were normally distributed, as assessed by Shapiro-Wilk’s test ($p = .579$). There were fewer social interactions when playing in LOF condition ($M = 20.000$ interactions, $SD = 13.075$) as opposed to the LEGO condition ($M = 21.030$ interactions, $SD = 13.047$). In addition, the LOF condition elicited a not statistically significant decrease in social interactions compared to LEGO condition, $M = -1.031$ interactions, 95% CI [-5.525, 3.462], $t(31) = -.468, p > .05$.

![Figure 8. Means and standard deviation for overt behaviors data of the ASC children in LOF and LEGO](image-url)
8.5. Appendix E

Boxplots of the paired differences of the overt behaviors of the non-ASC children’s data and the dyad’s data.

Figure 9. Box plots of the differences of each overt behavior of the non-ASC children’s data: (a) Social initiations, (b) Social responses, (c) Externalizations, and (d) Social interactions
Figure 10. Box plots of the overt behaviors of the dyad’s data: (a) Social initiations, (b) Social responses, (c) Externalizations, and (d) Social interactions
8.6. Appendix F

Graphs of the means and standard deviations for each overt behavior data of the non-ASC children and the dyad.

Figure 11. Means and standard deviation for overt behaviors data of the non-ASC children in LOF and LEGO

Figure 12. Means and standard deviation for overt behaviors data of the dyad in LOF and LEGO
8.7. Appendix G

Summary of the total number of outliers found in each event and the results obtained.

Table 6. Summary of the number of outliers and results found in changes on arousal activity

<table>
<thead>
<tr>
<th>EDA’s Feature:</th>
<th>Event:</th>
<th>Condition</th>
<th>LOF</th>
<th>LEGO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social responses – social initiations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of outliers</td>
<td>Statistical test</td>
<td>Sig. (2-tailed)</td>
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<td>Global Mean</td>
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<td>Sign test</td>
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</tr>
<tr>
<td>Externalizations – social initiations</td>
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<td>0</td>
<td>Sign test</td>
<td>.607</td>
</tr>
<tr>
<td>System log – social initiations</td>
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<td>2</td>
<td>Paired-samples t-test</td>
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</tr>
<tr>
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<td>4</td>
<td>Paired-samples t-test</td>
<td>.705</td>
</tr>
<tr>
<td>CDA SCR</td>
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<td>0</td>
<td>Paired-samples t-test</td>
<td>.793</td>
</tr>
<tr>
<td>System log – social initiations</td>
<td></td>
<td>3</td>
<td>Paired-samples t-test</td>
<td>.145</td>
</tr>
<tr>
<td>Social responses – social initiations</td>
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<td>4</td>
<td>Paired-samples t-test</td>
<td>.704</td>
</tr>
<tr>
<td>CDA ISCR</td>
<td></td>
<td>0</td>
<td>Paired-samples t-test</td>
<td>.793</td>
</tr>
<tr>
<td>System log – social initiations</td>
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<td>3</td>
<td>Paired-samples t-test</td>
<td>.145</td>
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<td>CDA AmpSum</td>
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<td>Sign test</td>
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<td>System log – social initiations</td>
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<td>Shapiro-Wilk’s</td>
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