Effectiveness of a Mixed Reality system in terms of social interaction behaviors in children with and without Autism Spectrum Condition

Olga Gali-Perez, Batuhan Sayis, Narcis Pares
Information and Communications Technologies
Pompeu Fabra University
Barcelona, Spain
olga.gali; batuhan.sayis; narcis.pares@upf.edu

ABSTRACT

The present study analyses the effectiveness of a mixed reality (MR) face-to-face full-body system to foster social interaction behaviors (SIBs) in a child with ASC and a play partner, a child without ASC (non-ASC). An MR system allows the development of an active and dynamic environment in which the therapist does not need to have a direct influence on individuals during the therapy. In this study, as part of a larger project, the main goals are to show (1) whether an MR system is as effective in fostering SIBs and non-stressful contexts of play in children with ASC as well as in non-ASC, and (2) whether an MR system has the potential to foster a higher number of SIBs and lower state anxiety levels compared to a traditional therapy setting (LEGO). Our results show that no significant differences were found in starting a new social sequence ("social initiation"), in externalizing "thoughts aloud" ("externalization"), and in SIBs as a whole ("social interaction") between ASC/non-ASC children both in LEGO and in the MR system. In addition, we found similar results when we compared both systems. There were also no significant differences related to state anxiety levels. These positive results show that an MR system is, at least, as good as a typical social intervention in promoting SIBs, as well as, in creating a non-stressful context of play; while an MR system has greater flexibility and a broad range of potential experiences.

CCS CONCEPTS

•Human-centered computing ~Human computer interaction (HCI) ~HCI design and evaluation methods ~Laboratory experiments •Social and professional topics ~User characteristics ~People with disabilities •Applied computing ~Law, social and behavioral sciences ~Psychology

Interacción '21, September 22–24, 2021, Málaga, Spain

ACM ISBN 978-1-4503-7597-9/21/09 $15.00
https://doi.org/10.1145/3471391.3471419

KEYWORDS

Autism Spectrum Condition, Social Interaction, Full-body Intervention, Mixed Reality, Virtual Reality, Augmented Reality, Therapy, Intervention, Social Play

ACM Reference format:

Olga Gali-Perez, Batuhan Sayis and Narcis Pares. 2021. Effectiveness of a Mixed Reality system in terms of social interaction behaviors in children with and without Autism Spectrum Condition: In XXI International Conference on Human Computer Interaction (Interacción '21), September 22–24, 2021, Málaga, Spain, *9 pages.* https://doi.org/10.1145/3471391.3471419

1 Introduction

As children, we tend to generate social interactions, share experiences, and feelings with other individuals who are part of society. The behavioral, emotional and social development of a person within society is based on their interactions and exchange of information with the other people who are part of that social context. Therefore, it is important to help people with social-communication difficulties to develop these skills so they can function efficiently in society. An efficient social interaction in childhood reflects an efficient social interaction in adulthood.

1.1 Interpersonal Communication in Autism Spectrum Condition

Autism Spectrum Condition (ASC) is a neurodevelopmental condition presented in early development [1]. According to the DSM-5, people who present ASC can exhibit different types of deficits, especially concerning social communication and social interaction. Social interaction is understood as a reciprocal process in which children effectively initiate and respond to social stimuli presented by their peers in diverse social settings and situations [2]. Nevertheless, people with ASC 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 present deficits in developing, maintaining and understanding relationships [1]. People who have high communication skills, such as being able to express their emotions, may be less stressed or anxious, than people who do not have such skills. Emotions can play a considerable role in the potential dysregulation of physiological stress responses [3]. The emotional state of a person could be defined, although not perfectly represented, as valence (positive versus negative) and arousal (excited versus calm), constituting a key aspect of communication [4, 5]. Therefore, a bidirectional process occurs between social communication and physiological systems [3].

Children with ASC can present a wide variety of symptoms and abilities. The assessment of communication, social interaction, and play or imaginative use of materials may be different among people with a diagnosis of ASC - hence the term spectrum [1, 6]. Therefore, high-functioning children with ASC are more likely to initiate or respond during peer interaction compared with low-functioning children with ASC [7]. Nonetheless, compared to non-ASC children, high-functioning children with ASC show more behaviors with minimal social enactment, such as ritualistic behaviors and maintaining close proximity, rather than performing prosocial behaviors, such as sharing feelings and experiences (high-level social behaviors) [7]. In addition, research has shown that they have less difficulties maintaining social interactions once these have been initiated; that is, their ability to respond to a partner's interaction is higher than their ability to initiate such interactions [8].

In children with ASC, the difficulties in social and communication skills can prevent learning, particularly learning through social interaction or learning in peer contexts [1]. Thus, the importance of developing interventions and tools to foster interpersonal communication skills.

1.2 Interpersonal communication interventions

Many behavioral treatments and interventions are available to improve the quality of life of people with ASC. Interventions and treatments are adjusted to address the person's specific needs since people with ASC can vary depending on the level and types of their symptoms and deficits. Traditionally, the most common therapies [9–15] require a specialist to mediate the intervention who often interferes with the process of generating social initiation behaviors. The emergence of technology and promising results on the affinity that children with ASC have towards the Information and Communication Technologies (ICT) [16] has allowed the development of more engagement and dynamic interventions and learning experiences [17]. 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) [17], virtual environments (VE) [18–20] and robotics [21–24]. These types of interventions focus on the development of active and dynamic systems in which the therapist does not need to have a direct influence on individuals during the therapy.

1.2.1 Full-body interaction interventions. Advances in technology allow the production of interventions that, despite being based on technology, do not require user-computer-and-mouse or mobile multitouch interaction. They focus instead on full-body interaction, which 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" [25], allowing for more intuitive and natural interaction with the environment [26]. Besides, full-body interaction technologies allow face-to-face collaboration and to assist learning. Researchers using full-body interaction techniques have shown positive results in fostering social behaviors [27–30]. The use of the body as a mediator for interactive experiences is based on the theories of Embodied Cognition. Embodied Cognition theory holds that the functionality of the mind must be understood in unison with the body [31]. The learning process is therefore produced by social activities among humans as constructors of knowledge (situated learning) [32], where meaning is created through collaborative interaction with others and the world around us [33]. Full-body interaction interventions have the advantage of being able to foster social and communicative interactions (verbal and non-verbal) between peers. It collocates multiple users in the same physical space allowing for a fluidity of awareness of others actions, creating a natural dynamic of collaboration, and allowing for implicit and immediate understanding between users. Moreover, it provides ecological validity as it is the most similar situation to real-life social interaction (as when children meet in a public park or the school playground) [34]. That is, children with ASC can practise their social and communication skills by interacting naturally with other children, without invasive or encumbering equipment.

1.2.2 Virtual environments and full-body interaction interventions. Virtual environments are suitable for interventions on children with ASC, which may be further enhanced by using full-body interaction, 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 through body movements [35], incorporating the use of gestures and non-verbal language, which are key to interpersonal communication [34]. Also, large-scale interactive full-body environments allow physical navigation and exploration of the medium, face-to-face interactions, and sharing feelings and experiences between users [28, 30].

1.3 Context and objectives

The present study is part of a larger project that uses an MR face-to-face full-body interaction experience to foster social initiations behaviors in children with ASC. Previous results show the positive effects and great potential of using an MR system to foster social interactions and collaborative behaviors in children with ASC while playing exploratorily with a child without ASC [30, 36].

In this study, the main purpose is to understand the effectiveness of an MR system in terms of SIBs comparing a child with ASC and a play partner, a child without ASC. Therefore, in the current study, the main goals are to show (1) whether an MR system is as effective in fostering SIBs and non-stressful contexts of play in children with ASC as well as in non-ASC, and (2) whether an MR system has the potential to foster a higher number of SIBs and lower state anxiety levels compared to a traditional therapy setting (LEGO).

2 Research methods

2.1 Hypothesis

In social and communication interactions, different overt behaviors can occur between users who interact. We classified the overt behaviors produced during both conditions (MR system and LEGO) according to whether they were "social initiations", "social responses" or "externalizations". We label as "social interaction" the sum of the total number of "social initiations", "social responses", and "externalizations". In the present study, we suggest two hypotheses in terms of overt behaviors and two hypotheses in terms of state anxiety levels.

Hypotheses for the overt behaviors:

- H1.1 There are no statistically significant differences in terms of the total number of SIBs between ASC and non-ASC children in the traditional therapy setting (LEGO) and in the MR system.

- H1.2 There is a significantly higher total number of SIBs in the MR system compared to the traditional therapy setting (LEGO) for both ASC and non-ASC children.

Hypotheses for the state anxiety levels:

- H2.1 There are no statistically significant differences in terms of the state anxiety level between ASC and non-ASC children in the traditional therapy setting (LEGO) and in the MR system.

- H2.2 There are significantly lower state anxiety levels after the MR system compared to the traditional therapy setting (LEGO) for both ASC and non-ASC children.

2.2 Population

In this study, we developed the experiments in user trials with dyads of children: a child with high-functioning ASC and a child without ASC. A total amount of seventy-two children (36 ASC/non-ASC dyads) participated from the city of Barcelona, with ages between 8-12 years old (N = 12 female, N = 60 male). Recruited ASC children had been diagnosed with high-functioning ASC through the scale of Observation for the Diagnosis of Autism (ADOS) module 3 having a minimum severity diagnosis of 4 [6]. Children without a diagnosis for ASC or other conditions were recruited through dissemination on social media and in schools. Additionally, both ASC and non-ASC children had to score a minimum IQ of 70 as determined by the Wechsler Intelligence Scale for Children [37].

2.3 Ethics

The procedures performed during the sessions followed the 1964 Helsinki declaration, while the ethics committee of the hospital we collaborated with asked for subsequent amendments and then granted ethical approval for conducting the sessions. We gathered consents to participate from parents through an informed consent form, which detailed the goals and procedures of the project, as well as assents from the children on the day of the trial to make sure they were willing to participate. All data has been kept anonymous and under our university's approved data safety protocols.

2.4 Experimental design and set up

At the beginning of the session, the psychologist welcomed the children and created the first contact with them. In a relaxed environment, the psychologist explained the session and used the visual support tool called "Jumby is Calm" [38], as used in social skills therapy, to anticipate possible reactions from the children during the session. Having gained the children's attention and trust by the psychologist, a researcher fitted a kid-friendly wearable, designed by our lab for recording psycho-physiological measurements, on them. The ASC and non-ASC dyads were exposed to two conditions in a single experimental session: the MR system (experimental condition) and the traditional intervention setting (control condition). Each pair of children played each of the conditions once for 15 minutes, with a 5 minutes break between them. The assignment of the order of the conditions was carried out randomly to counterbalance the order effect of the tasks. Before the children played in the MR system, they were introduced to the physical object they need to interact with the VE (a technified butterfly net), and watched an introductory video of how they should use it. Before and after each condition, they were given questionnaires. In addition, before each condition and at the end of the session, the children performed standard relaxation activities guided by the psychologist.

2.4.1 The Mixed Reality System: Lands of Fog (LOF). The MR system was designed and developed to foster social initiations in children with ASC while playing with children without ASC, of the same age and gender. The system is based on a face-to-face full-body virtual environment in which a natural dynamic of collaboration and exploration is fostered, allowing implicit and immediate understanding between users and providing an ecological validity. Users experiment and share their experiences in a 6-meter diameter circular playing area projected by two full HD projectors (see Fig. 1A, B). The interaction with the virtual environment and the elements within it occurs through a physical object with LED lights. This object in the shape of a butterfly net allows the children to focus their attention on the environment. The movement of the butterfly net is tracked by a camera tracking system. In addition, the design of the VE, animations, and characters were created through a Participatory Design Workshop [39].

The sounds and visuals, the changes in the characters and objects, as well as the surprise factors, allow the development of a dynamic and active intervention in which a child with ASC plays and communicates with a child without ASC, without needing direct external mediation from a psychologist. For a further description of the game design and its characteristics, refer to Mora-Guiard et al. [40].

2.4.2 The traditional intervention setting: LEGO game. The traditional therapy intervention was created based on Daniel Legoff's therapy. Legoff obtained positive results in improving the acquisition of social skills in children with ASC [41]. We needed this condition to match as much as possible the conditions defined by the MR experience; i.e. embodied interaction, ambulatory exploration and collaboration, possibility of close proximity and distant activity, standing position with downward looking attitude, etc. Therefore, to play the LEGO game, we especially designed and built a hexagonal-shaped table that allows the fluid movement of children around it (as opposed to statically playing on the floor). The centre of the table is the space used to build different constructions and we placed a container with LEGO pieces at each of its vertices (see Fig. 1C). It is a passive system in which the therapist modulates the activities: initially, the children look for pirate-themed figures in the containers, while later they build a ship for the figures.

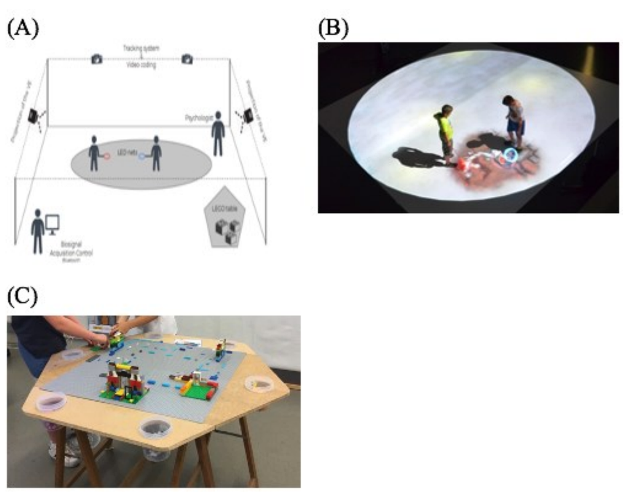

Figure 1: Experimental conditions. (A) Configuration of the MR system. (B) Two children playing collaboratively in the MR experience. (C) Two children playing collaboratively in the traditional therapy setting (LEGO).

3 Data analysis

3.1 Data gathering

3.*1.1. Overt behaviors.* To effectively evaluate the outcomes of the face-to-face full-body interaction experience of the dyad, all sessions were recorded. Two GoPro Hero 4 cameras equipped with two sensitive Rode microphones were positioned on opposite sides about 50 cm outside the limit of the interactive space, which provided a wide-angle view and audio of the entire interaction space. For the evaluation of the overt behaviors, and in alignment with previous studies [7, 42–48], a categorical scheme was used. The scheme was based on the evaluation of Bauminger of social-emotional understanding in children with ASC [7], which we subsequently adapted with the help of the experts in ASC of Hospital Sant Joan de Déu and the psychologist of the project. The SIBs produced by the children were categorized as "social initiation", "social response", and "externalization". The coding of the videos was done with the BORIS video coding software [49]. The recorded conversations were transcribed by native Spanish and Catalan speakers to facilitate subsequent video coding. 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.

To categorize the SIBs we defined the following categories:

- Social initiation. The child begins a new social sequence verbally or nonverbally. Also, it is distinguished from a continuation of a previous sequence.

- Social response. The child responds verbally or nonverbally to a specific social stimulus directed toward him/her by peers.

- Externalization. The overt behavior was not strictly directed towards the play partner. This is an important behaviour since it could potentially be picked up by the partner to continue a social exchange.

3.1.1.1 Video Coding Reliability. The intercoder reliability of the video coding scheme was calculated for each category (occurrence of social initiations, responses and externalization), both through percentage agreement and Cohen's Kappa. Kappa scores were between 0.60 to 0.69 and the percentage level of agreements were between 0.71 to 0.78 with three coders.

3.1.2 State anxiety level. 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 [34]. The 20 items used to know the feelings of the children at a certain moment, were read aloud to each child while the tablet screen was shown. Therefore, the child could read the question and mark the answer. The inclusion-exclusion criteria followed was to include only data with all the items answered.

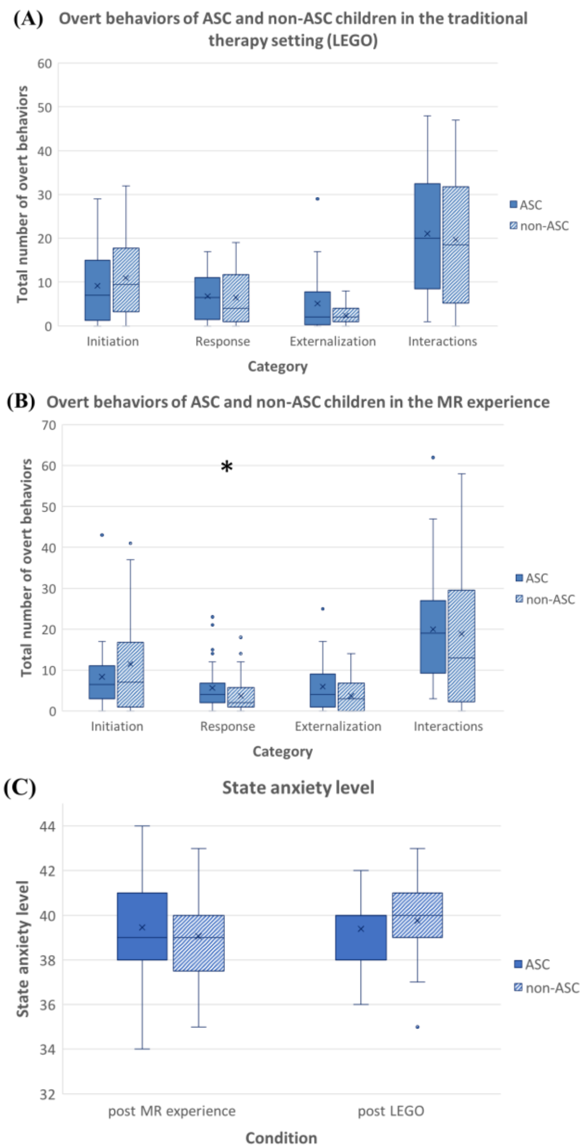

Figure 2: Boxplots for (A) the total number of overt behaviors of ASC and non-ASC children in the traditional therapy setting: LEGO, (B) the total number of overt behaviors of ASC and non-ASC children in the MR system, and (C) the state anxiety levels in ASC and non-ASC after the MR experience and the traditional therapy setting: LEGO.

3.2 Results

The participants were the same individuals tested under the two different conditions: the MR system and LEGO. A paired-sample t-test was used to search for significance ($p < .05$). In addition, a Shapiro-Wilk test was run to check for normality in the data distribution. A Wilcoxon signed-rank test was used if the data was nonparametric.

3.2.*1* Results for H1.1 and H2.1.

3.2.1.1 The LEGO condition. When ASC and non-ASC were compared in LEGO there were no significant differences between them in either the total number of social initiations (t(31) = 0.935, p = 0.357), social responses (t(31) = -0.443, p = 0.661), externalizations (t(31) = 1.848, p = 0.065), and social interactions (t(31) = -0.555, p = 0.583) nor the state anxiety level (t(32) = -1.338, p = 0.181) (see Fig. 2A,C). We found non-significant differences in terms of social initiations done by the non-ASC children (M = 10.940, SD = 8.944) towards the ASC children (M = 9.160, SD = 8.313). In addition, the non-ASC children elicited non-significant differences in terms of social responses (M = -0.344, SD = 4.389), externalizations (M = -2.750, SD = 7.269), and social interactions (M = -1.312, SD = 13.372) done in the LEGO condition compared to ASC children.

3.2.1.2 The MR system condition. On the one hand, in terms of the total number of SIBs in the MR system we found different results when ASC children were compared with non-ASC children. There were no statistically significant differences in social initiations (t(31) = -0.715, p = 0.475), externalizations (t(31) = 1.770, p = 0.077), and social interactions (t(31) = -0.488, p = 0.629) between non-ASC and ASC children (see Fig. 2B). However, we found there were more statistically significant responses done by the ASC children in the MR system (M = 5.660 responses, SD = 5.807) in comparison with the non-ASC children (M = 3.690 responses, SD = 4.368). The non-ASC children elicited a statistically significant decrease in social responses done in the MR system compared to ASC children, M = -1.969 responses, 95% CI [-0.878, -0.60], t(31) = -2.104, p = .044. On the other hand, there were non-significant differences in terms of state anxiety level between non-ASC (M = 39.061 SA level, SD = 1.936) and ASC children (M = 39.455 SA level, SD = 2.425) after the MR experience (figure 2C), M = -0.394 SA level, 95% CI [-1.461, 0.673], t(32) = -0.752, p = 0.458.

3.2.2 Results for H1.2 and H2.2. In previous hypotheses, we compared non-ASC children with ASC children in the MR system and in LEGO. For hypotheses H1.2 and H2.2 we found differences between the MR system and LEGO condition in non-ASC children but non-significant differences in ASC children.

3.2.2.1 ASC children. When the MR system and the LEGO condition were compared in ASC children, we found there were non-significant differences between them in either the total number of social initiations (t(31) = -0.571, p = 0.572), social responses (t(31) = -1.223, p = 0.231), externalizations (t(31) =

0.810, p = 0.422), and social interactions (t(31) = -0.468, p = 0.643) nor the state anxiety level (t(32) = 0.407, p = 0.684).

Refer to Table 1 to see the mean and the standard deviation of each overt behavior and state anxiety level on each factor.

Table 1. Mean and standard deviations for each dependent variable (rows) and each factor (columns).

	Non-ASC children in the MR experience	Non-ASC children in LEGO	ASC children in the MR experience	ASC children in LEGO	Difference between non-ASC/ASC in the MR experience	Difference between non-ASC/ASC in LEGO
Social initiations	11.500 ± 12.529	10.940 ± 8.944	8.340 ± 7.897	9.160 ± 8.313	3.156 ± 12.150	1.781 ± 10.782
Social responses	3.690 ± 4.358	6.440 ± 6.221	5.660 ± 5.807	6.438 ± 4.963	-1.970 ± 5.294	-0.344 ± 4.389
Externalizations	3.690 ± 4.020	2.340 ± 2.209	5.970 ± 6.024	5.094 ± 6.770	-2.281 ± 6.783	-2.750 ± 7.270
Social interactions	18.880 ± 18.043	19.720 ± 14.550	20.000 ± 13.075	21.030 ± 13.047	-1.125 ± 13.048	-1.313 ± 13.371
State anxiety level	39.061 ± 1.936	39.758 ± 1.640	39.455 ± 2.425	39.758 ± 1.640	-0.394 ± 3.010	0.364 ± 2.059

3.2.2.2 Non-ASC children. In terms of SIBs in the non-ASC children (H1.2), we found different results when the MR system was compared with the LEGO condition. There were no statistically significant differences in social initiations (t(31) = 0.316, p = 0.754), and social interactions (t(31) = -0.335, p = 0.740). However, we found there were marginally statistically significant differences in the total number of externalizations (t(31) = 1.997, p = 0.055). In addition, the non-ASC children elicited a statistically significant decrease in social responses done in the MR system compared to LEGO condition, t(31) = -2.882, p = 0.005. On the other hand, there were no significant differences in terms of state anxiety level between the MR system and LEGO condition for non-ASC children, M = -0.607 SA level, 95% CI [-1.482, 0.088], t(32) = -1.808, p = 0.080.

3.2.2.3 Difference between non-ASC and ASC children. We computed the difference between non-ASC and ASC for each SIB. We found no statistical differences in any of the SIBs. Therefore, we found there were non-significant differences between the MR system and LEGO condition in the total number of social initiations (t(31) = 0.778, p = 0.442), social responses (t(31) = 0.651, p = 0.515), externalizations (t(31) = 0.431, p = 0.670), and social interactions (t(31) = 0.104, p = 0.918). In addition, there were non-significant differences in the state anxiety level (t(32) = -1.385, p = 0.176).

3.3 Complexities of the study

One of the complexities of the study was the diversity of the data. The main purpose of the study was to understand if there was an interaction between the two independent variables ("type of condition" and "condition of children") on the dependent variables ("overt behaviors" and "state anxiety level"). Therefore, we had one between-subjects factor ("condition of children") and one within-subjects factor ("type of condition").

Because of our type of data, we tested a two-way mixed ANOVA procedure to see possible interactions between the factor of the type of experience condition (LEGO/MR system) and the factor of the children condition (non-ASC/ASC). Nonetheless, despite applying a number of different transformations on the data, we could not get it to comply with the assumptions required by the two-way mixed ANOVA. Therefore, we used different paired-samples t-tests instead. A paired-samples t-test could be used when (i) same individuals are tested under two different conditions (LEGO/MR system in our study), and (ii) you have two groups of participants that have been matched on one characteristic (children diagnosed or not with ASC in our study) and tested on one dependent variable (in our study overt behaviors and state anxiety level).

4 Discussion

From our review of the state of the art, this is the first system of this type developed for ASC children to exercise in social initiation behaviors. Therefore, our contribution is the first to analyse the effectiveness of a face-to-face full-body MR system in terms of SIBs between non-ASC children and ASC children. For the analysis of the MR system, we analyzed the SIBs for each condition (MR system/LEGO) and factor (ASC/non-ASC) through coding of recorded videos and the levels of state anxiety of the children post-experiences through the STAIC questionnaires.

4.1 Social interaction behaviors

The first objective of the study was to analyze if there were any differences between children with and without ASC in each of the experimental conditions: LEGO and the MR system.

Initially, we analyzed if there were any differences in the control condition, LEGO. The results showed there were no statistically significant differences between ASC and non-ASC children in any of the SIBs categories. The LEGO setting is a passive system that seems to foster SIBs in both children. It could be explained since LEGO is a very common play tool for children. The results show reliability in the use of the LEGO system as a control system as there were no significant differences between the children in the dyads.

The MR system showed similar results. There were no significant differences between ASC and non-ASC children when we evaluated the total number of "social initiations", "externalizations", and "social interactions". However, we found a significant decrease in the total number of "social responses" produced by non-ASC children when compared to children with ASC. The MR system allows children to perform a wide variety of dynamic activities while they are experimenting with the VE [40]. Some of the dynamic activities that children can carry out in the developed MR system are: the progressive discovery of the VE by partially removing a dense virtual fog that covers all the environment; capture fireflies situated in the environment which then change to the color of their butterfly nets and are under their control thereafter; see the emergence and evolution of different fantastic characters that follow the user; and interact with different virtual elements that lie about in the VE. The dynamism of the environment allows children to create and project imaginatively through virtual characters and elements. This effect could explain the significant differences found between non-ASC and ASC children in terms of the total number of "social responses". Non-ASC children, as opposed to children with ASC [1], have better imaginative abilities when they play in imaginative games. This ability could make non-ASC children be more immersed in the MR system and focus their attention on both exploring the environment and interacting more with the characters and the virtual elements. Therefore, the MR system seems to block the continuity of SIBs in non-ASC children once these have been initiated by their play partner. This was a very unexpected result since it is usually understood that immersion is a positive factor in any virtual, augmented or mixed reality experience. However, it can be easily understood that in an MR experience we need a balance between the virtual and the physical worlds in the experience. The balance is necessary because the children share the physical world while interacting with the virtual world. If the balance is broken and one of the children focuses too much on the virtual world, the physical world (i.e. the other child) is lost from sight and tends to be ignored.

In social and communication contexts between pairs, it is important to have a system that is equally effective regardless of the diversity in children involved in the interaction. The SIBs of a child are influenced by the interaction of the other. We can conclude that our MR system has great potential in fostering SIBs, concretely in categories such as "social initiations", being one of the main difficulties in children with ASC [1], "externalizations", and "social interactions" as a whole.

The second objective was to analyze whether the MR system was able to foster a higher total number of SIBs when it is compared with the control condition, LEGO. Analysis of the results showed that the differences in the SIBs in children with and without ASC were not significantly higher in the MR system compared to LEGO. However, we did not find significant differences in terms of SIBs between the MR system and the LEGO condition produced by children with ASC towards non-ASC children. The results could be explained by the affinity that children with ASC have towards ICT [16]. It promotes and motivates ASC children to participate in the MR system as they would do in a known game, such as in LEGO construction. In conclusion, the MR system is, at least, as good as the LEGO condition in fostering SIBs in children with ASC towards non-ASC children. However, is the MR system as good as the LEGO condition in fostering SIBs in non-ASC? The results showed that the total number of "social responses" done by non-ASC children was significantly lower in the MR system and the total number of "externalizations" was almost significantly higher in the MR system in comparison with LEGO. It seems there was a tendency to encourage "externalizations" and to cover up "social responses" in the MR system, compared to LEGO. In alignment with the previous results of the present study, the progressive discovery of the environment, the characters and the virtual elements of the MR system seems to cover up the social responses of non-ASC children, possibly due to their immersion in the game. Regarding this result, new interactive designs should explore the possibility of showing the entire environment without being covered by some virtual element and, also, without the existence of characters that could promote the higher immersion of non-ASC children. Therefore, it is possible that new designs with more visual abstract elements and with an entire visualization of its environment could foster a higher total number of "social responses" in non-ASC children by making them being less immersed in the game, and, as a consequence, being more open to SIBs with the play partner. A new system with these characteristics is under development in our laboratory. Apparently, the MR system keeps non-ASC children playing longer with the game, but the system seems to allow them and motivate them to express their thoughts about the action in the game in a sort of spontaneous "think aloud". This seems a positive result since it looks like the type of gameplay that the MR system offers appears to help children to open up and externalise their inner thoughts, desires, and preferences.

4.2 State anxiety level

The third objective was to analyze possible differences in state anxiety levels between children (ASC/non-ASC) and different types of conditions (MR system/LEGO). The results showed that there were no significant differences in any of the cases. The results could be explained since children are in face-to-face full-body interactions, being similar interactions to what they would find in a natural environment such as in the school playground and/or in public parks. In this regard, the advantage that an MR system offers us, compared to a passive system, is that children can move freely through a large space without being forced to interact. The latter could be more reflected in non-ASC children who showed marginally significantly lower state anxiety levels after the MR system experience, compared with LEGO. The results are of great interest since positive contexts of play could reflect higher SIBs [3]. Future research should further contemplate and analyze the interactions that occur between state anxiety levels and SIBs in face-to-face full-body interactions.

5 Conclusions and future work

The understanding of SIBs in children is important since each individual in a social interaction influences the social interaction of others, this being a bidirectional process [50]. In an MR system the influence that children exert on each other through their collaborative SIBs allows them to give meaning to the knowledge produced during the experience and their relation [32, 33]. The MR system developed encourages both the production and the understanding of social meaning by fostering face-to-face full-body interactions in dyads. Therefore, children are in the same context influencing verbally and nonverbally each other. Children can improve their social and communication skills, encouraging learning through social interaction and through peer contexts. However, in future research, new interactive environments should be developed to encourage the continuity of SIBs in non-ASC children once the interaction has been initiated. As we have seen, different virtual environments and elements should be considered to reduce the immersion of the non-ASC children in the game. In other words, better balance the virtual and physical world in the MR experience. The great flexibility of an MR system allows for exploring a broad range of potential experiences, and for addressing to all range of children. It promotes diversity. Future design research should be done to explore more the dynamism and opportunities that the MR system allows.

In addition, with the present study, we have seen the effect that an MR system has in terms of SIBs in a dyad of play: a child with ASC and a child without ASC. That is, without grouping children due to their condition [18, 21, 51, 52]. Hence, an MR system has the potentiality of avoiding social prejudices in child play and, therefore, promoting an inclusive play; i.e. seeing the other as a suitable play partner. Future research could design a system that is more accessible to schools.

Moreover, further research on interpersonal communication between a child with ASC and a child without ASC should be done to analyze better the influence of each individual in the SIBs context. The analysis of interpersonal relationships is important since it has an effect on later psychological development [53]. It promotes learning, maturation, socialization and evolution as an individual in society. Therefore, undertaking longitudinal studies should allow us to see how the experiences and processes produced at a specific developmental stage can modify the responses of that individual at a later time.

ACKNOWLEDGMENTS

This work has been funded by Spanish Ministry of Economy and Competitiveness under the Maria de Maeztu Units of Excellence Program (MDM-2015-0502). We would like to thank Sant Joan de Déu for their help and collaboration. And finally, thank you to all the children and their families who participated in the study.

REFERENCES

1. American Psychiatric Association (2013) American Psychiatric Association, 2013. Diagnostic and statistical manual of mental disorders (5th ed.)
2. Brady MP, Shores RE, McEvoy MA, et al (1987) Increasing social interactions of severely handicapped autistic children. J Autism Dev Disord. https://doi.org/10.1007/BF01487067
3. Knapp ML, Daly JA (John A (2011) The Sage handbook of interpersonal communication, Fourth edi. SAGE Publications
4. Picard RW (2009) Future affective technology for autism and emotion communication. Philos Trans R Soc B Biol Sci 364:3575–3584. https://doi.org/10.1098/rstb.2009.0143
5. Doyran M, Türkmen B, Oktay EA, et al (2019) Video and text-based affect analysis of children in play therapy. ICMI 2019 - Proc 2019 Int Conf Multimodal Interact 26–34. https://doi.org/10.1145/3340555.3353760
6. Kim SH, Lord C (2018) Autism Diagnostic Observation Schedule BT - Encyclopedia of Clinical Neuropsychology. In: Kreutzer JS, DeLuca J, Caplan B (eds). Springer International Publishing, Cham, pp 432–436
7. Bauminger N (2002) The Facilitation of Social-Emotional Understanding and Social Interaction in High-Functioning Children with Autism: Intervention Outcomes. J Autism Dev Disord 32:283–298. https://doi.org/10.1023/A:1016378718278
8. Bauminger-Zviely N, Eytan D, Hoshmand S, Rajwan Ben–Shlomo O (2020) Preschool Peer Social Intervention (PPSI) to Enhance Social Play, Interaction, and Conversation: Study Outcomes. J Autism Dev Disord 50:844–863. https://doi.org/10.1007/s10803-019-04316-2
9. Pierce WD, Cheney CD, Pierce WD, Cheney CD (2018) Applied Behavior Analysis. In: Behavior Analysis and Learning. Routledge, pp 435–470
10. Vismara LA, Rogers SJ (2008) The Early Start Denver Model. J Early Interv 31:91–108. https://doi.org/10.1177/1053815108325578
11. Hess EB (2015) DIR®/Floortime™: A Developmental/Relational Play Therapy Approach Toward the Treatment of Children With Developmental Delays, Including Autism Spectrum Disorder (ASD) and Sensory Processing Challenges. In: Handbook of Play Therapy: Second Edition
12. Cermak SA, Borreson AE (2016) Occupational therapy. In: Health Care for People with Intellectual and Developmental Disabilities Across the Lifespan. Springer, Cham, pp 1053–1067
13. Gutstein S, Burgess AF, Montfort K (2007) Evaluation of the relationship development intervention program. Autism 11:397–411. https://doi.org/10.1177/1362361307079603
14. McLaughlin MR (2011) Speech and language delay in children. Am Fam Physician 83:1183–1188
15. Koegel LK, Koegel BL, Koegel RL, Vernon TW (2015) Pivotal Response Treatment. In: Children and Youth with Autism Spectrum Disorder (ASD). Oxford University Press
16. Brown J, Murray D (2001) Strategies for enhancing play skills for children with autism spectrum disorder. Educ Train Ment Retard Dev Disabil 36:312–317
17. Boucenna S, Narzisi A, Tilmont E, et al (2014) Interactive Technologies for Autistic Children: A Review. Cognit Comput 6:722–740. https://doi.org/10.1007/s12559-014-9276-x
18. Parsons S, Beardon L, Neale HR, et al (2000) Development of social skills amongst adults with Asperger's Syndrome using virtual environments: the'AS Interactive'project. Proc 3rd Int Conf Disabil Virtual Real Assoc Technol ICDVRAT. https://doi.org/10.1.1.112.2969
19. Parsons S, Leonard A, Mitchell P (2006) Virtual environments for social skills training: comments from two adolescents with autistic spectrum disorder. Comput Educ 47:186–206. https://doi.org/10.1016/j.compedu.2004.10.003
20. Marto A, Almeida HA, Gonçalves A (2019) Using Augmented Reality in Patients with Autism: A Systematic Review. In: Lecture Notes in Computational Vision and Biomechanics. Springer Netherlands, pp 454–463
21. Duquette A, Michaud F, Mercier H (2008) Exploring the use of a mobile

robot as an imitation agent with children with low-functioning autism. Auton Robots 24:147–157. https://doi.org/10.1007/s10514-007-9056-5

22. Dautenhahn K, Ogden B, Quick T (2002) From embodied to socially embedded agents - Implications for interaction-aware robots. Cogn Syst Res. https://doi.org/10.1016/S1389-0417(02)00050-5
23. Duquette A, Michaud F, Mercier H (2008) Investigating the Use of a Mobile Robotic Toy as an Imitation Agent for Children with Autism. Auton Robot – Spec Issue Soc Assist Robot
24. Robins B, Dickerson P, Stribling P, Dautenhahn K (2004) Robot-mediated joint attention in children with autism: A case study in robot-human interaction. Interact Stud Stud Soc Behav Commun Biol Artif Syst. https://doi.org/10.1075/is.5.2.02rob
25. Malinverni L, Pares N (2014) Learning of abstract concepts through full-body interation: A systematic review. Educ Technol Soc
26. Chen W (2012) Multitouch tabletop technology for people with autism spectrum disorder: A review of the literature. In: Procedia Computer Science
27. Lindley SE, Le Couteur J, Berthouze NL (2008) Stirring up experience through movement in game play: effects on engagement and social behaviour. In: Proceedings of the SIGCHI Conference on Human Factors in Computing. CHI '08, pp 511–514
28. Mora-Guiard et al. - 2016 - Lands of Fog helping children with Autism in social interaction through a full-body interactive experience.pdf
29. Crowell C, Sayis B, Benitez JP, Pares N Mixed Reality, Full-Body Interactive Experience to Encourage Social Initiation for Autism: Comparison with a Control Nondigital Intervention. https://doi.org/10.1089/cyber.2019.0115
30. Mora-Guiard J, Crowell C, Pares N, Heaton P (2017) Sparking social initiation behaviors in children with Autism through full-body Interaction. Int J Child-Computer Interact 11:62–71. https://doi.org/10.1016/j.ijcci.2016.10.006
31. Dourish P (2001) Where the Action Is: The Foundations of Embodied Interaction. Where action is Found embodied Interact. https://doi.org/10.1162/leon.2003.36.5.412
32. Rambusch J, Ziemke T (2005) The role of embodiment in situated learning. … 27th Annu Conf …
33. Fuchs T, de Jaegher H (2009) Enactive intersubjectivity: Participatory sense-making and mutual incorporation. Phenomenol Cogn Sci. https://doi.org/10.1007/s11097-009-9136-4
34. Crowell C (2018) Analysis of interaction design and evaluation methods in full-body interaction for special needs. In: 23rd International Conference on Intelligent User Interfaces, Proceedings IUI. IUI '18, pp 673–674
35. Parés N, Masri P, Van Wolferen G, Creed C (2005) Achieving dialogue with children with severe autism in an adaptive multisensory interaction: The "MEDIATE" project. IEEE Trans Vis Comput Graph. https://doi.org/10.1109/TVCG.2005.88
36. Crowell C, Sayis B, Benitez JP, Pares N (2019) Mixed Reality, Full-Body Interactive Experience to Encourage Social Initiation for Autism: Comparison with a Control Nondigital Intervention. Cyberpsychology, Behav Soc Netw cyber.2019.0115. https://doi.org/10.1089/cyber.2019.0115
37. Weiss LG, Locke V, Pan T, et al (2019) Wechsler Intelligence Scale for Children—Fifth Edition: : Use in Societal Context. In: Weiss LG, Saklofske DH, Holdnack JA, Prifitera A (eds) WISC-V, Second Edi. Academic Press, pp 129–195
38. Gallo K AJ (2009) Eye power 2. https://www.amazon.com/Power-Learning-Your-Activity-Coloring/dp/B0050E3OJK. Accessed 30 Mar 2020
39. Schaper MM, Iversen OS, Malinverni L, Pares N (2019) FUBImethod: Strategies to engage children in the co-design of Full-Body interactive experiences. Int J Hum Comput Stud 132:52–69. https://doi.org/10.1016/j.ijhcs.2019.07.008
40. Mora-Guiard J, Crowell C, Pares N, Heaton P (2016) Lands of fog: Helping children with Autism in social interaction through a full-body interactive experience. Proc IDC 2016 - 15th Int Conf Interact Des Child 262–274. https://doi.org/10.1145/2930674.2930695
41. LeGoff DB (2004) Use of LEGO© as a therapeutic medium for improving social competence. J Autism Dev Disord 34:557–571. https://doi.org/10.1007/s10803-004-2550-0
42. Hauck M, Fein D, Waterhouse L, Feinstein C (1995) Social initiations by autistic children to adults and other children. J Autism Dev Disord. https://doi.org/10.1007/BF02178189
43. McMahon CM, Vismara LA, Solomon M (2013) Measuring changes in social behavior during a social skills intervention for higher-functioning children and adolescents with autism spectrum disorder. J Autism Dev Disord. https://doi.org/10.1007/s10803-012-1733-3
44. Bauminger-Zviely N (2019) The Autism Preschool Peer Interaction Observation Scale (APIOS): Naturalistic Observation to Assess Social-Communicative Skills during Ongoing Interaction with Peers
45. Herbrecht E, Lazari O, Notter M, et al (2019) Process research in early intensive intervention in autism spectrum disorder: Sensitivity to change of the autism behavior coding system. Autism Res 12:1817–1828. https://doi.org/10.1002/aur.2188
46. Kitzerow J, Teufel K, Wilker C, Freitag CM (2016) Using the brief observation of social communication change (BOSCC) to measure autism-specific development. Autism Res 9:940–950. https://doi.org/10.1002/aur.1588
47. Locke J, Shih W, Kretzmann M, Kasari C (2016) Examining playground engagement between elementary school children with and without autism spectrum disorder. Autism. https://doi.org/10.1177/1362361315599468
48. Bakker S, Markopoulos P, De Kort Y (2008) OPOS: An observation scheme for evaluating head-up play. In: ACM International Conference Proceeding Series
49. Friard O, Gamba M (2016) <scp>BORIS</scp>: a free, versatile open-source event-logging software for video/audio coding and live observations. Methods Ecol Evol 7:1325–1330. https://doi.org/10.1111/2041-210X.12584
50. Burgoon JK, Stern LA, Dillman L (1995) Interpersonal Adaptation: Dyadic Interaction Patterns. Cambridge University Press
51. Francis GA, Mareva S, Farr W, Gibson JL (2018) Do Tangible User Interfaces promote social behaviour during free play? A comparison of autistic and typically-developing children playing with passive and digital construction toys. https://doi.org/10.31234/osf.io/vz83a
52. Bai Z, Blackwell AF, Coulouris G (2015) Using augmented reality to elicit pretend play for children with autism. IEEE Trans Vis Comput Graph 21:598–610. https://doi.org/10.1109/TVCG.2014.2385092
53. Mouton G (2014) Interpersonal Communication. DE GRUYTER