Hybrid Approach to Promote Social Interaction with Children with Autism Spectrum Disorder

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Abstract: The comprehension of the emotional state of others is paramount for a successful human interaction. Individuals with Autism Spectrum Disorder (ASD) have impairments in social communication and, consequently, they have difficulties to interpret others' state of mind. In order to tackle this issue, researchers have been proposing the use of technological solutions to assist children with ASD, particularly in imitation and emotion recognition tasks. Social robots and Objects with Playware Technology (OPT) have been employed as intervention tools with children with ASD. This work presents an approach combining both technologies (robots and OPT), in a hybrid way, with the goal of promoting social interaction with children with ASD. Moreover, a new OPT device was developed to be used as an add-on to the human-robot interaction with children with ASD in two emotion recognition tasks – recognize and storytelling. A pilot study was conducted with children with ASD to evaluate the proposed method. All children successfully participated in the activities. Moreover, children significantly gazed longer towards the OPT during the storytelling scenario as the OPT device displayed visual cues, supporting that using a visual cue may be fundamental in helping children with ASD understand requests and tasks.

1 INTRODUCTION

Autism Spectrum disorder (ASD) is a neurodevelopment disability that affects 1 in 54 individuals. It is characterized by the diagnostic criteria that include impairments in social communication and social interaction, with the existence of restricted, repetitive patterns of behaviour, or activities that may continue throughout life (American Psychiatric Association, 2013). The diagnosis can be done correctly in early stages of life (around the 36 months of age). Due to the diversity and specificities of symptoms, developing effective intervention is still challenging.

In order to tackle this issue, new forms of intervention have been explored and conducted in the last years by employing the use of technological devices such as robots, tangible interfaces/Objects with Playware Technology (OPT) and mechanical components, among others. Indeed, some studies (Dautenhahn & Werry, 2004; Tapus et al., 2012) conducted by using technological tools showed that children with ASD have great affinity with them. In particular, it has been shown that individuals demonstrated improvements in social behaviours such as imitation (Fujimoto, Matsumoto, de Silva, Kobayashi, & Higashi, 2011), eye gaze, and motor ability, while increasing attention (Kim, Paul, Shic, & Scassellati, 2012) when interacting with robots. Moreover, it was also identified that children with ASD may exhibit certain positive social behaviours when interacting with robots in contrast to what is perceived when interacting with their peers, caregivers, and professionals (Gillesen, Barakova,

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Huskens, & Feijs, 2011). In addition to being repeatable and objective, social robots are designed to identify, measure, and react to social behaviours, offering an exceptional occasion for quantifying social behaviours (Tapus, Member, & Scassellati, 2007). Therefore, robots may be very promising on intervention settings with children with autism, especially in tasks such as emotion recognition and collaborative peers' interaction.

Several physical designs, ranging from simple designs such as four-wheeled mobile robots (Ferrari, Robins, & Dautenhahn, 2009) to many levels of anthropomorphic forms, including humanoid (Soares et al., 2019), animal-like (Breazeal, 2000), and machine-like systems (Michaud et al., 2005), have been used. Since the robot's physical appearance plays an important role in the interaction process with a person, recent research in the area of social robots have been consistently using robots with a humanoid-like design (Pennisi et al., 2016), especially in tasks of imitation and emotion recognition, offering a great potential for generalisation. The FACE (Mazzei et al., 2011) and ZECA (Soares et al., 2019) projects use facial expressive humanoid robots in emotion recognition tasks to promote social interaction with individuals with ASD.

Analogous to the use of social robots, OPT devices have also been used as a form of interaction with children with ASD. With the goal of offering playful experiences to the end user, these devices are tangible interfaces developed for children's play (Lund, Klitbo, & Jessen, 2005). The term "playware" is suggested as a combination of intelligent hardware and software, emphasizing the role of interplay between morphology and control using processing, input, and output.

Few works focusing on OPT with different configurations such as modular buttons, coloured puzzle tiles (Lund & Marti, 2009), *Lego*-like building blocks (Barajas, Al Osman, & Shirmohammadi, 2017), interactive screens (Boucenna et al., 2014), among others have been proposed. An example of a work where OPT devices were used with children with ASD consisted in designing interactive tiles as a modular robotic playware with the goal of being flexible in both setup and activity building for the end user, allowing easy creation of games (Lund, Dam Pedersen, & Beck, 2009). The tiles had a quadratic shape with self-contained energy source and wireless communication (local and global), and different games. An example of a game conducted during experiments with children with ASD consisted in mixing the tiles in different combinations to produce more colours. More specifically, there were three main tiles with fixed colours (mainly red, green, and blue), and using the secondary tiles (a total of 12), with the property of changing their colours accordingly to their neighbours colour, a new colour could be created by mixing the neighbours tiles colours. For example, if a secondary tile was placed between two main tiles of colours red and blue, the middle tile (secondary) would change its colour to purple, blending the two main colours. The experiments carried out with seven children with ASD allowed the authors to conclude that devices built with playware technology may offer an interesting novel research direction. Through this research direction, this issue will be further investigated in order to verify how playware can be used as playful tool for cognitive challenged children, giving them a playful experience and automatically infer the playful interaction to provide insight (and possible a diagnosis).

Following this trend, it was proposed and evaluated a novel approach combining both technologies (robots and OPT), in a hybrid way, with the goal of promoting social interaction with children with ASD (Silva, Soares, Esteves, & Pereira, 2018). The present work shows the developments of this approach as well as the development of a new OPT device to be used as an add-on to the human-robot interaction with children with ASD in emotion recognition tasks. This hybrid approach was evaluated through experiments conducted with these children. The main goal of the pilot study was to assess the constraints of both the game design as well as the OPT rather than to evaluate the performance of each child.

The rest of this paper is organized as follows: Section 2 presents the proposed approach with the description of the OPT; Section 3 shows the results; Section 4 discusses the results obtained; the conclusions and future work are addressed in Section 5.

2 MATERIAL AND METHODS

This section provides the description of the developed OPT with the procedures followed to evaluate the current proposed approach.

2.1 Proposed System

The system, depicted in Fig. 1, consists of a facial expressive humanoid robot, a processing unit, and the OPT device PlayBrick.

The humanoid robot used is the model *Zeno R50* from *Robokind*. ZECA (Zeno Engaging Children with

Autism) has a child-like appearance with 34 degrees of freedom: 4 being located in each arm, 6 in each leg, 11 in the head, and 1 in the waist. The robot is capable of expressing facial expressions thanks to the servo motors mounted on its face and a special material, Frubber, which has a similar look and feel to human skin.

Figure 1: Proposed system setup. Starting from the left: the developed OPT (PlayBrick), central processing unit, and the humanoid robot ZECA.

The Robokind software performs animation and motion control functions and it includes an Application Programming Interface (API) for rapid integration of other components and shared control.

Regarding the OPT, the design approach consisted in developing a device that can offer a tangible experience, adapt itself to different games scenarios and provide immediate feedback. It was designed with the purpose of being used in different activities and contexts by physically (re)programming it or by adding new components such as sensors. This may offer an exceptional opportunity to measure behaviours since children with ASD are less willing to use wearable devices (Bekele, Crittendon, Swanson, Sarkar, & Warren, 2014), which may be a challenge when trying to extract additional behaviour information. The addition of feedback from the OPT to the user is a key feature that allows guiding the child through the play activity and to enjoy the experience in all its fullness. Since the users expect to see and feel the results of their actions, the immediate feedback feature is a very important factor specially when designing devices for children with impairments. Furthermore, learning via reinforcement can be one of the most effective approaches to reinforcing desired behaviours, particularly with children with ASD, allowing the formation of an association between a suggestion or action and a reinforcement with some intrinsic motivational value (Schuetze, Rohr, Dewey, McCrimmon, & Bray, 2017). Since the experience should be configurable, the type of feedback should also be adaptable according to the child preferences. For example, some types of feedback may be uncomfortable for some children with ASD, such as the sound feedback that may be unenjoyable since some individuals are oversensitive to environmental stimuli (Schoen, Paul, & Chawarska, 2011).

Following these ideas, the developed OPT, PlayBrick (Fig. 2), was designed to provide a tangible and adaptive experience, being easy and intuitive to manipulate through natural gestures (such as touch, tilt, rotation), with different sources of immediate feedback (haptic and visual). The PlayBrick has a 5.0-inch touch screen, an Inertial Measurement Unit (IMU), a haptic driver with a Linear Resonant Actuator (LRA), and a LED RGB strip. It has built-in Bluetooth and Wi-Fi communication.

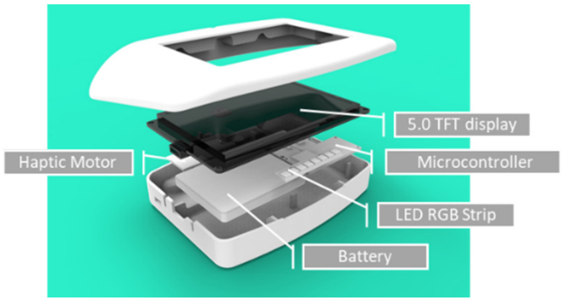

Figure 2: General view of the PlayBrick and its main components.

2.2 Designing the End User Activity

The developed activities are focused on emotion recognition tasks. The first task, denominated recognize, consists in the robot displaying randomly one of the five basic facial expressions (happiness, sadness, anger, surprised, and afraid) and its associated gestures (body posture), Fig. 3. Then, the child is prompted to identify the emotion associated with the facial expression.

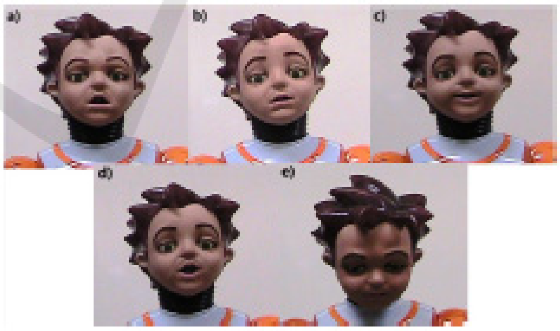

Figure 3: The different facial expressions displayed by the robot ZECA: a) anger, b) fear, c) happiness, d) surprise, and e) sadness (Soares et al., 2019).

The second task is the storytelling game, in which randomly selected stories among 15 social stories are told by the robot, and the participant has to identify the emotion of the main actor, i.e. the robot (Fig. 4). The identification of emotions displayed by other people is essential (Clark, Winkielman, & McIntosh, 2008), being fundamental for successful social interactions. As most children with ASD have alterations in the central auditory processing, vision is one of the strongest skills of individuals with ASD (Caldeira da Silva et al., 2012), meaning that using a visual support can be fundamental in helping children with ASD understand requests and tasks. Therefore, each social story has its associate visual representation of the story scenario. As the robot starts telling the story, an image is simultaneously shown representing the social context of the story as a visual cue (Fig. 4). Then, the child is prompted to answer how the robot felt in that story scenario.

In both game scenarios, the child selects the answer by tilting back and forward the PlayBrick, scrolling through the facial expressions (common emoji) displayed by the OPT and touching the image.

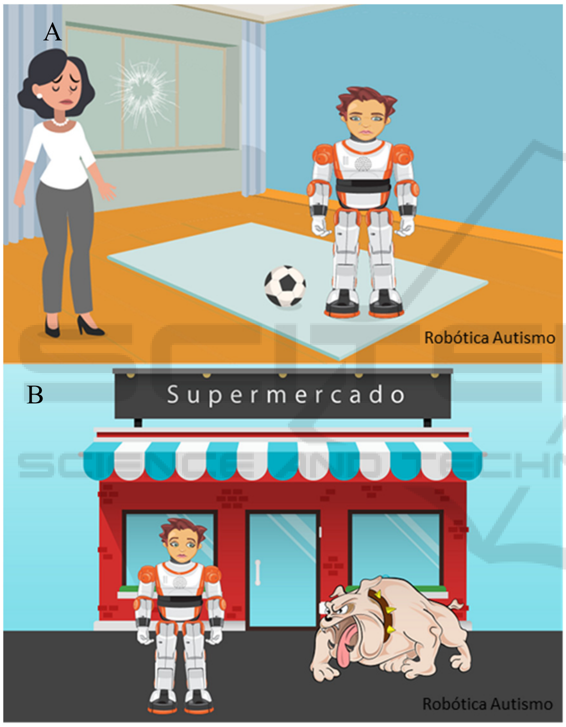

Figure 4: Sample of images for the storytelling game scenario. The scenario A represents the sad emotion, with the following story: "*I like to play when I'm at home. Today I took my ball and played with the ball in the living room. I kicked strongly the ball and broke a window. My mother me scolded me and I cried.*" The visual cue B represents the fear emotion, with the following story: "*I go with my mother shopping. I like to choose the yogurts that I eat. Today, at the exit of the supermarket, a very large dog began barking very loud. I was shaking.*"

The type of input is also configurable, meaning that if a child has difficulties in manipulating (tilting) the device, the interface changes by showing two arrows that also allow the participant to search and select the possible answer (Fig. 5). In parallel, when the answer is selected, a positive or negative reinforcement is prompted by ZECA and the PlayBrick. The type of reinforcement is configurable on both the robot and the OPT according to the child preferences.

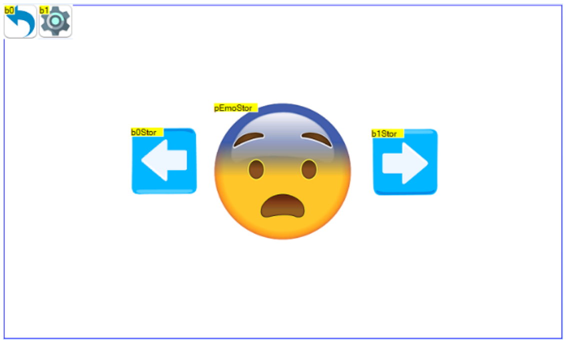

Figure 5: Prompted interface to the child on the OPT screen to select the answer. The arrows are visible in case the child has difficulties in manipulating the PlayBrick.

2.3 Procedures and Participants

Tests following the experimental design in Fig. 6 were conducted in a school environment in a triadic setup, i.e., child-robot-researcher. The goal of the pilot study was to detect the systems constraints and verify if the system can implement a procedure that makes the children able to interact in a comfortable and natural way during an intervention session.

In the experimental setup used in the school, the child sits in front of the robot, which is positioned at approximately 85 cm from the child's line of sight. Two cameras are placed behind the robot in order to video record the sessions. One camera (A) records only the child and camera B records the overall session. The researcher is seated next to the child in order to assist the child during the task. This layout is proposed in order to establish a basis of comparison between the participants along the sessions, since the experiments are conducted in an unconstrained (in this case a school) but familiar setting for the child.

All procedures involving the children with ASD during the study were conducted in accordance with the following ethical concerns: the research work was approved by the ethical committee of the university of Minho, a collaboration protocol was firmed between the university and the school, and informed consents were signed by the parents/tutors of the children that participated in the studies.

A sample of 4 children previously diagnosed with ASD aged 6 to 10 years (*M= 8.75*; *SD=0.96*) was selected to participate in this study. From here on, the children are identified as A, B, C, and D. Although ASD is more prevalent in boys (Christensen et al., 2016), the selected sample has as many boys (2) as girls (2). All children that participated in the study are verbal but their attempts to initiating interactions and make friends are odd and typically unsuccessful – which corresponds to level 1 of severity levels of DSM5 in 2013. The participants are high functioning, according to their diagnosis.

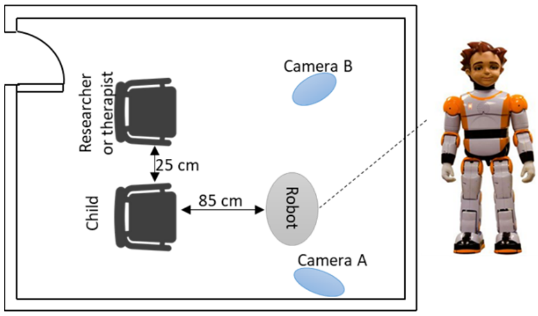

Figure 6: The experimental design used during the experiments in a triadic configuration: child, robot, researcher.

According to the therapists, the type of reinforcement used in the study was the same for three children (robot: verbal + movement + sound; PlayBrick: visual + haptic) and different from one child (robot: verbal + movement; PlayBrick: visual + haptic).

The study was carried out during four sessions spaced one week between the second and the third session. In the first session the children played the recognize game scenario. The storytelling activity was conducted in the 3 remaining sessions (Fig. 6).

2.4 Analysis

The videos of the experiments of the 4 sessions were coded by one observer specialized in behavioural psychology. To assess the children's engagement during the activity, the frequency of children's gaze towards to the robot and to the PlayBrick as well as the duration of such events were registered. The number of times that the children needed help and the number of wrong usages of the PlayBrick were counted. Additionally, the number of correct, incorrect, and unanswered answers as well as the number of total robot prompts during the sessions were quantified. The children's mean response time to the robot's prompts were also registered. At the end of each session, the robot asked the participant if he/she wanted to play more. This was also quantified. The non-parametric Wilcoxon signed-rank test (alternative to parametric paired t-test) was used to compare the children's attention during the storytelling game scenario. This test will be reported by using the Z statistic.

3 RESULTS

A set of experiments were carried out in a school setting involving four children with ASD (children A, B, C, and D). Both activities (recognize and storytelling) were played.

Regarding the children's attention it was found that, in general, children gazed more towards to the robot in the first session (recognize game scenario), Fig. 7. In the other sessions (storytelling) the children tended to gaze more at the OPT device.

Furthermore, the children's mean duration per gaze, in general, was higher towards the PlayBrick than towards the robot (Fig. 8). In particular, the children's mean duration per gaze in the storytelling game scenario was significantly less for the gazes directed at the robot ($M=5.28$; $SD=1.76$) than those directed at the PlayBrick ($M=12.58$; $SD=2.97$), $Z=-3.059$, $p<0.001$.

Figure 9 shows the number of right and wrong answers, as well as the number of no answered prompts. In general, it is possible to notice a positive evolution, regarding the number of successful answers along the sessions. Moreover, the participants answered all of the robot's prompts.

In general, the children's mean response time to the robot prompts increased between the first session (where the recognize activity occurred) and the second session (where the storytelling game scenario was played), Fig. 10-A. Regarding sessions 3 and 4, the children's mean response time remain, in general, unchanged.

Additionally, the number of times that a child needed help (Fig. 10-B) on how to manipulate the PlayBrick decreased over the sessions.

During the study only one child manipulated wrongly the PlayBrick, two times, being assisted by the researcher on how to correctly manipulate de device.

Table 1 shows the sessions where each participant answered positively ('✓') to the robot asking if he/she wants to play more.

Table 1: The sessions where the children wanted to continue the activity ('✓').

Child	Session			
	1	2	3	4
A	✓	✓	✓	-
B	✓	-	-	-
C	-	✓	-	-
D	-	✓	✓	✓

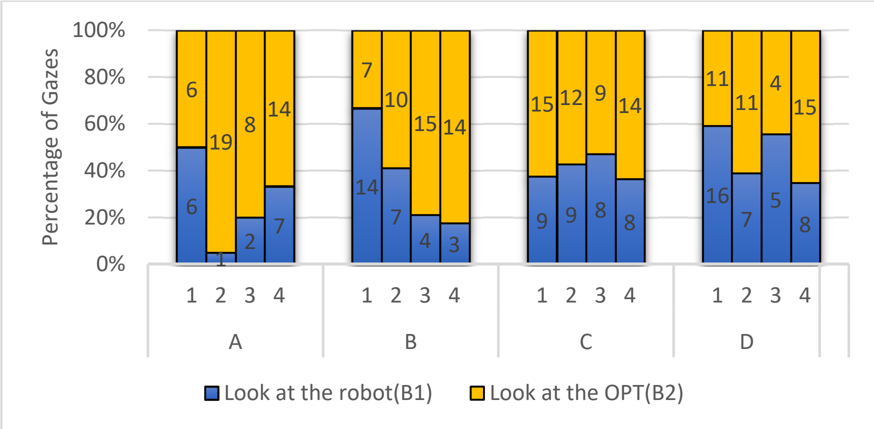

Figure 7: Percentage and number of gazes towards the robot and the PlayBrick for the 4 children (A, B, C, and D) during the sessions for the game scenarios recognize (session 1) and storytelling (sessions 2, 3, and 4). It is possible to perceive that, overall, the children gaze more towards to the robot in the first session. In the remaining sessions, children tended to look more at the PlayBrick.

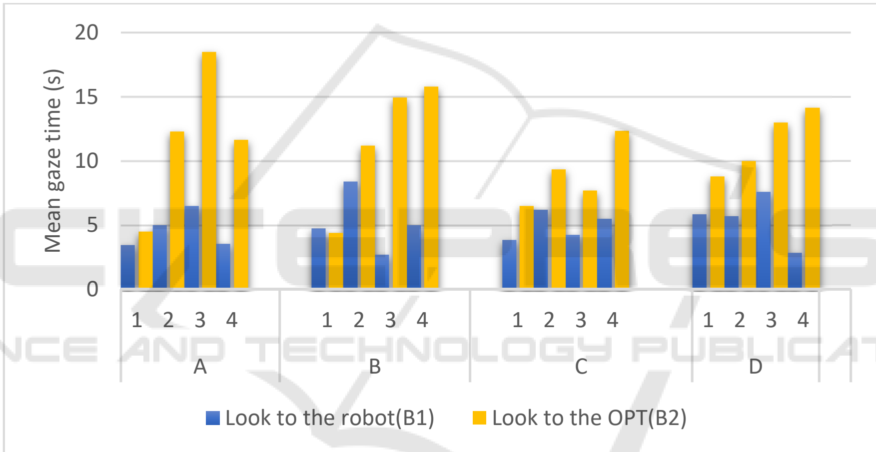

Figure 8: Mean gaze time towards the robot and the PlayBrick for the 4 children (A, B, C, and D) during the sessions for the game scenarios recognize (session 1) and storytelling (sessions 2, 3, and 4).

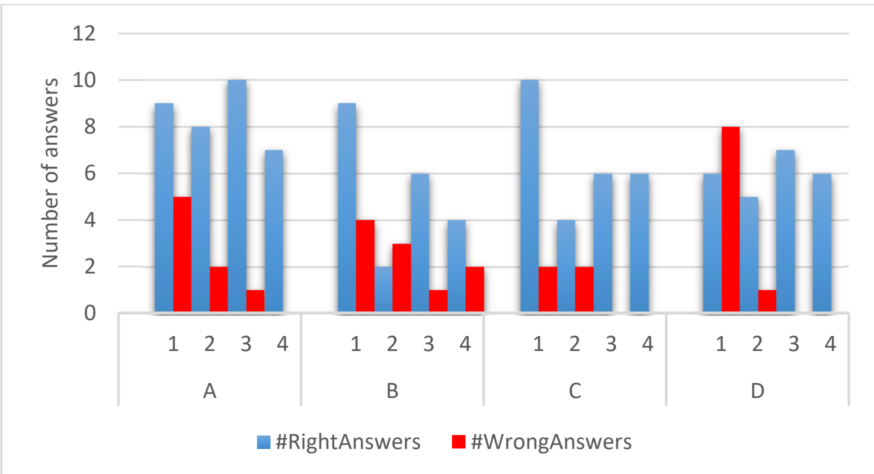

Figure 9: Children's answers to the robot prompts during the four sessions.

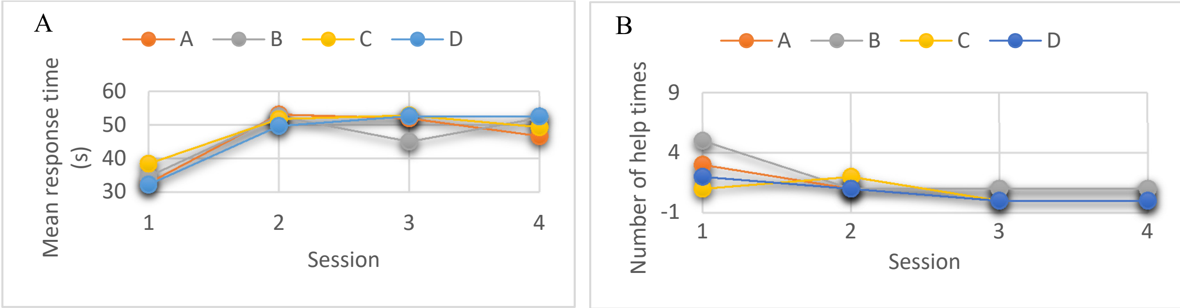

Figure 10: A – Children's mean response time in seconds (with confidence interval) to the robot prompts during the four sessions. B – Number of times that each child need help to interact with the PlayBrick over the four sessions.

4 DISCUSSION

Concerning children's attention in the activity, there were more gazes towards the robot during the first session compared to the other sessions (Fig. 7), since during this activity the child had to look at the robot face in order to identify the robot facial expression. However, the mean gaze time towards to the robot, in general, was lower when compared to the mean gaze time towards the PlayBrick, Fig. 8. The mean gaze time towards the OPT was significantly higher (p-value lower than 0.05 significance level) during the sessions where the storytelling game was conducted, indicating that the children relied on the storytelling visual cues displayed by the PlayBrick. This supports that the use of visual cues may be paramount for children with ASD to understand the tasks. In addition, the children answered all prompts and the number of right answers were superior to the number of wrong answers (Fig. 9), further supporting that the children understood the games and successfully interacted with the PlayBrick. Moreover, the children rapidly adapted and learned how to interact with the OPT and the robot, since the number of times that each child needed help during the activities decreased over the sessions, Fig. 10-B.

The mean response time to the robot prompts during the storytelling activity was higher when compared to the recognize activity (Fig. 10-A), which is expected since during this activity the child has to identify the state of mind of the main character of the story.

In general, all children wanted to continue the activities (Table 1), meaning that they enjoyed and were successfully engaged in the activities. Additionally, it is worth mentioning that none of the children that participated in this study ever abandoned an activity.

5 CONCLUSIONS

The comprehension of social emotional cues is important for a successful human communication. However, individuals with ASD present impairments in social communication. New forms of intervention have been explored and conducted in the last years by employing the use of technological devices trying to mitigate the emotion recognition impairments that children with ASD present.

Following this idea, the present work shows the developments of a hybrid approach in human-robot interaction with children with ASD in emotion recognition tasks. This hybrid approach includes the OPT device PlayBrick, used as an add-on to the humanoid robot intervention.

By analysing the results, it is possible to conclude that the children understood the mechanics of the games and successfully interacted with PlayBrick. There was a significant difference in the mean gaze time towards the OPT, particularly in the storytelling scenario, suggesting that the children used/relayed on the PlayBrick during the activities. Moreover, in general, the children were keen to participate in the activities since they wanted to continue on playing. Additionally, they were also attentive to the PlayBrick feedback, lights, haptic as well as the images for correct and incorrect answers displayed on the screen.

The future work includes further improvements of this hybrid approach. A study will be conducted involving a larger sample of children with ASD to understand if and how the presented method may be used as a valuable tool to promote social interaction with children with ASD.

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