25th IEEE International Symposium on
Robot and Human Interactive Communication (RO-MAN)
August 26-31, 2016. Columbia University, NY, USA

Joint Attention Using Human-Robot Interaction: Impact of Sensory Preferences of Children with Autism*

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Abstract— **Individuals suffering from Autistic Spectrum Disorder (ASD) have impaired skills in social communication and joint attention. In this paper, we explain how we designed and evaluated a Joint Attention (JA) task for individuals with ASD using the Nao humanoid robot. The interaction was tested in children and teenagers with ASD (N=11). Their proprioceptive and visual integration of cues were first assessed, with the hypothesis that individuals with an overreliance on proprioceptive cues and with a hyporeactivity to visual cues would have more difficulties conducting successful interactions with the robot. We observed that participants with an overreliance on proprioceptive cues and hyporeactivity to visual cues showed different behaviors in responding to joint attention. They followed the prompting of the Nao robot more slowly than individuals with an overreliance on visual cues and a hyporeactivity to proprioceptive cues. Defining such individual profiles prior to the social interaction with a robot and working closely with caregivers could provide promising strategies for designing successful and adapted Human-Robot Interaction (HRI) for individuals with ASD.**

I. Introduction

A. *Integration of Proprioceptive and visual integration of cues in ASD*

Individuals with Autistic Spectrum Disorder (ASD) have impaired skills in communication, interaction, emotion recognition, joint attention, and imitation [1]. Motor, sensory, and visual processing impairments are also present, but they are not included in the ASD diagnosis [2], [3]. An overreliance on proprioceptive information is also suggested. Proprioception can be defined as a person's ability to determine his/her own body segment positions (i.e., joint position sense) and detect his/her own limb movements (kinesthesia) in space. It is derived from complex somatosensory signals provided to the brain by multiple muscle [4]–[6], joint [7], and skin receptors [8]. Individuals with autism show normal to exacerbated integration of proprioceptive cues compared with typically developed individuals (TDI) [3]. Proprioceptive integration in ASD has been studied to gain a better understanding of how these cues influence interactive and social capacities. In [9], the authors observed that the greater the reliance on proprioception, the more children with ASD exhibited impairments in social function and imitation. Moreover, limited visual processing skills lead to difficulties in social interactions. Vision is an important component of communication and social behaviors. An impairment in visual processing and gaze functions in individuals with ASD may lead to unusual eye contact, difficulty following the gaze of others, difficulty supporting joint attention, and difficulty interpreting facial and bodily expressions of emotion [2]. In addition, visual field-dependent individuals are considered more group-oriented, cooperative, and less competitive than visual field-independent individuals [10]. Visual field-dependent individuals are strongly interested in people and get closer to the person with whom they are interacting, while visual field-independent individuals appear to be cold and detached; they are socially isolated but have good analytic skills [11].

B. *Joint Attention Skills in ASD*

Joint Attention (JA) deficits are used as a clinical sign for an ASD diagnosis [12]. Joint attention reflects the degree to which an individual coordinates attention with a social partner toward objects, thanks to pointing and/or gaze direction [13]. The development of joint attention begins in the first year of life: at approximately eight months, an infant is able to follow his/her parents' gaze. At 10-12 months, children begin to follow a moving target point [12]. Joint attention is an essential, typical, and spontaneously occurring behavior in human communication and is involved in learning. Joint Attention appears to be impaired in individuals with ASD [12], [13]. Individuals with ASD tend to have impaired production and comprehension of joint attention behaviors. They do not use gestures or other strategies, such as finger pointing and grasping the hand of an adult, to share interest in objects or their properties, and they have impaired responses to joint attention requests [1], [12], [13]. Intervention approaches for increasing joint attention have shown positive effects on social learning and development in individuals with ASD [12], [13] and are

*This work is supported by IdF Doctoral Fellowship FRANCE, 2013, HANDICAP theme.

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978-1-5090-3929-6/16/$31.00 ©2016 IEEE

encouraged when a child is diagnosed with ASD [12]. Several interaction therapies are used to reinforce or learn joint attention behaviors. They vary along the naturalistic-discrete-trial continuum: naturalistic interactions are similar to parent-child interactions, and discrete interactions use training and practice methods [14].

C. Robots in Joint Attention Therapy for Individuals with Autism

Many studies have shown that children with ASD have a great affinity with robots, computers, and mechanical components [15]. In the field of Socially Assistive Robotics (SAR) [16], robots are used as tools in socialization therapies for children with ASD to enhance social engagement, imitation, or joint attention skills. Using a robot for joint attention therapies with individuals with ASD raises several questions: several studies showed that, compared with a human partner, a robot needs to elicit more prompting to obtain a joint attention response from children [16], [17]. However, in [18], the authors observed that joint attention therapy on a small group (N=6) enables children to improve their joint attention skills. A common task in joint attention therapies with robots consists of prompting the child to look in a given direction using increasing levels of information from the robot (moving the head / moving the head and pointing with the arm) and the target (static image / image and music / video) [16]–[18]. To the best of our knowledge, no study has examined the sensorimotor and visual profiles of individuals suffering from ASD to determine and elaborate individualized and personalized scenarios for Human-Robot social interaction therapy.

D. Objectives and Hypothesis

Our long-term goal is to elaborate interaction models for therapy purposes that can be individualized with respect to the sensorimotor and visual profiles. Our current study aims to develop a new personalized social interaction model between a humanoid robot and an individual suffering from ASD to enhance his/her social and communication skills. To define relevant individuals' profiles, we posit that the individual's reliance on proprioceptive and kinematic visual cues will affect the way the individual interacts with a humanoid robot [9]-[11]. We hypothesize that in ASD, a mitigated behavioral response (i.e., hyporeactivity) to visual motion and an overreliance on proprioceptive information are linked to difficulties integrating social cues and engaging in successful interactions (**H1**).

E. Previous work

1) Participants

We conduct our research in collaboration with two care facilities for people suffering from ASD: *IME MAIA* (France) and *IME Notre Ecole* (France), associations for children and teenagers with ASD. Our subject pool is composed of 11 children with ASD (11.9±2.59 years old) from these two care facilities. There are nine male and two female participants. For confidentiality reasons, we coded the participants' identities as follows: CH#, with # from 1 to 11.

2) Proprioceptive and Visual Preferences

In our previous work [19], we developed a method to define each participant's perceptivo-cognitive and sensorimotor profiles with respect to the integration of visual inputs. First, we assessed with a force platform the effect of a moving virtual visual scene on postural control and the individuals' capability to use proprioceptive inputs provided in dynamics of balance to reduce visual dependency [20]. Secondly, we used the Adolescents/Adults Sensory Profile (AASP) questionnaire, that assess the individual's sensory processing preferences in terms of neurological thresholds for stimulation (high-low) and self-regulation strategies (active-passive) [21]. Clustering analysis (dendogram, Ward method) on the results of the AASP and the experimental setup allowed us to identify three groups with significant different behavioral responses to the moving virtual visual scene. The reader can find a more detailed description of this clustering phase in [19].

Group G1 (participants: CH3; CH5; CH8; CH10; CH11) high scores in Movement Sensory Sensitivity (MSS) and visual sensation seeking, low scores in Visual Sensory Sensitivity (VSS) and strong visual independence to the moving virtual visual scene, suggesting an overreliance on proprioceptive cues and hyporeactivity to visual cues.

Group G2 (participants: CH1; CH4; CH7; CH9) moderate scores in MSS and low scores in visual sensation seeking, low scores in VSS and moderate reactivity to the moving virtual visual scene, suggesting they relied evenly on visual and proprioceptive cues.

Group G3 (participants: CH2; CH6) high scores in VSS and low scores in MSS and in visual sensory seeking, and hypereactivity to the moving virtual visual scene, suggesting a hyporeactivity to proprioceptive cues and a overreliance on visual cues.

Thanks to these three groups and the profiles we defined, we are able to analyze the social, interaction, and emotion recognition skills of our participants in regard to our hypothesis.

F. Current Work

In this paper, we present the design of a joint attention task for individuals with ASD, tested with our subject pool of 11 children and teenagers with ASD. Thanks to the joint attention task, we aim to validate the relevance of the proprioceptive and visual individual profiles we defined in [19] as a prerequisite to maximize robot influence (usability) to facilitate joint attention and improve social interaction. We search to validate our hypothesis H1. More precisely, we hypothesize that:

H2A. An individual with an overreliance on proprioceptive cues and a hyporeactivity to visual cues will have difficulties reading the intention of the robot.

H2B. An individual with an overreliance on visual cues and a hyporeactivity to proprioceptive cues will have an easier time reading the intention of the robot.

In our setup, we controlled the level of complexity of bodily signals displayed by the robot. The robot displayed different levels of prompting (*Head only*; *Arm only;* and *Head & Arm*). We hypothesize that:

H3. Individuals with an overreliance on visual cues should more easily read the prompting of the robot than individuals with a hyporeactivity to visual cues, regardless of the level of prompting.
For the matching game, we used 15 cards divided into three subsets of visual difficulties, described in Section II. Overall, individuals who are independent of visual cues should achieve better results in the Hidden Figures Task than individuals who are dependent of visual cues [22]. From this, we posit that:
H4. An individual with a hyporeactivity to visual cues should make fewer mistakes selecting matching cards (confusing the same object in different sets).

The rest of the paper is organized as follows: Section II describes the design and the evaluation protocol of the joint attention task. Section III presents the results of the interaction between the robot and the eleven children with ASD. Section IV concludes the paper with a detailed discussion on the results obtained.

II. Matching Game with the Nao Robot

A. Design

With the help of the caregivers, we designed a matching game involving a joint attention task. This type of game is interesting for us for the following reasons: (1) it allows us to assess the perception and integration of visual cues; (2) we were able to design it to assess joint attention skills, and it can be tested on its capacity to reinforce joint attention; and (3) it can easily be adapted to individuals by using different images (with various levels of details).

B. Method

The experimental setup for the task is shown in Figure 1. We used the mini-humanoid robot Nao from Aldebaran Robotics to conduct the joint attention task. Nao is sitting on a desk. A Kinect camera is placed on top of it with the help of a wooden structure built for this experiment. Two identical monitors are used; one is positioned on Nao's right, and a second on its left. In addition to the recording from the Kinect, we used two other cameras to record the interaction. The participant sits in front of the Nao robot next to the caregiver. The experimenter is behind, hidden from the participant and the caregiver, and follows the experiment procedure on a laptop. The paper cards to match are lying on the desk between the participant and the Nao robot. The participant has to select and show the robot the same image as the one displayed and prompted to him/her on one of the monitors.
We tested different levels of prompting. The robot prompted the participant with a sentence to look at one of the monitors (right of left) and by a movement of its (1) *Head only*, (2) *Arm only*, and (3) *Head & Arm*. The movements were selected in a random order with five movements in the *Head only* condition, five movements in the *Arm only* condition, and five movements in the *Head & Arm* condition. The right and left monitors were also selected randomly. We used 15 cards for the matching game, divided into three subsets of visual difficulties. The images in the first subset are simple drawings (Figure 2), the ones in the second subset are more complex drawings (Figure 3), and the ones in the third subset are photos (Figure 4). Each subset is composed of five images: a tree, a bike, a car, a house, and a teddy bear. The cards are composed of the images printed on white paper on squares with sides 6 cm long, glued on a blue squared cardboard with sides 10 cm long.

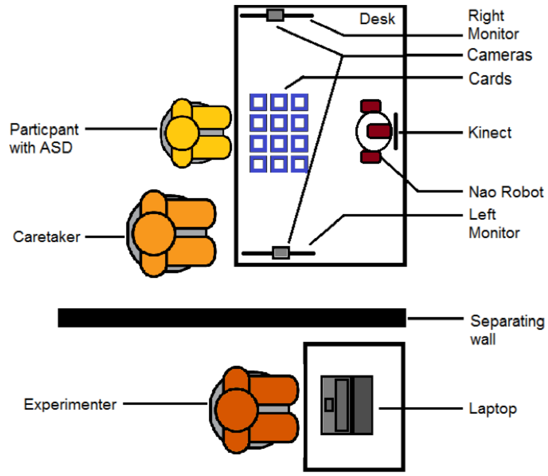

Figure 1 Setup of the Joint Attention task experiment

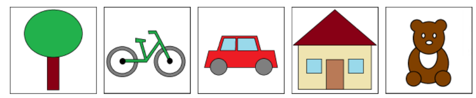
Figure 2 Images of the first subset (very simple sketches with a small number of details). From left to right: Tree1; Bike1; Car1; House1; Bear1

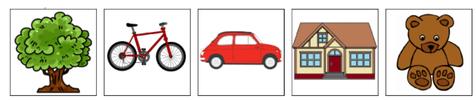
Figure 3 Images of the second subset (sketches closer to the reality with more details than in the first subset). From left to right: Tree2; Bike2; Car2; House2; Bear2


Figure 4 Images of the third subset (real images with real objects found in our daily life). From left to right: Tree3; Bike3; Car3; House3; Bear3

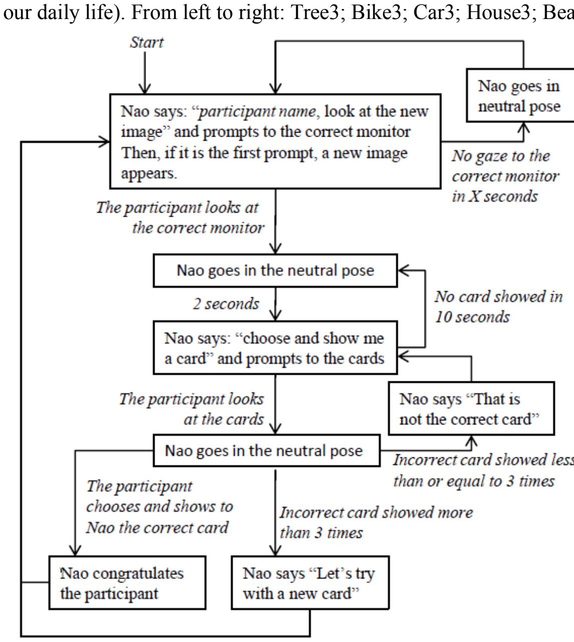

Figure 5 Diagram of the game stages with the robot Nao

Before starting the interaction, the way to show cards to Nao was explained to the participants. We taught children with ASD how to show the cards with an example set formed by two cards that were not used in the experiment (rabbit and dog drawings). This part was performed several times until the child with ASD was able to correctly show the cards to the robot.

The interaction stages are as follows: (1) Greetings: Nao says, "Hello, I am happy to see you, *participant name*!", while looking at him/her; (2) Game: Matching game, see Figure 5; and (3) Goodbye: Nao says goodbye to the participant, "Goodbye, *participant name*, see you soon!". The caregiver is instructed not to interact with the participant during the entire session to avoid inducing joint attention.

The interaction was partly simulated using a Wizard of Oz (WoZ) model. The interaction was originally automated thanks to the Kinect and a face tracker that enabled us to track the face of the participant and its orientation. The experimenter, however, was able to override the program at any time during the interaction. During the experiment, the children with ASD were indeed difficult to track. They hid their heads with their hands or the cards, or they looked straight down. These issues forced us to finally only lead the interaction thanks to the experimenter, as a WoZ setup.

C. *Measures*

With this experiment, we were willing to test our hypotheses. We wanted to verify that the behavior of our participants was linked to their proprioceptive and visual profiles. We already assessed the individual profiles of our participants using the combination of the AASP score and an experimental setup (see Section 1.5). To analyze the behavior of the participants, we collected the following parameters to assess their social skills, taking inspiration from the Early Social Communication Scales (ESCS) [23] and existing Human-Robot Interaction metrics.

Response to joint attention (RJA): good following of pointing and gaze of the robot. We observe if the participant missed or looked at the wrong monitor when prompted.

Time of response of RJA (TRJA): the time between the beginning of the movement of the robot and the moment the participant's eyes hit the screen.

Mistakes: we observed their answers during the matching game and noted their mistakes and correct responses.

A first coder (first author) annotated all of the videos of the interaction. A second coder, unaware of the hypotheses of the setup, annotated a certain percentage of the videos. The Cohen Kappa Coefficient (κ) and Intraclass Correlation Coefficient (ICC) were used to ensure inter-coder reliability (see Table 1).

D. *Participants*

We worked with our subject pool of 11 children and teenagers with ASD (11.9±2.59 years old) (see Section 1.5.1). In Table 2, we give a short description of each participant and their corresponding groups as defined in Section 1.5.2.

TABLE 1 Inter-Coder Reliability

	Inter-Coder Reliability	Percentage of data inter-coded
Answer to prompting	κ=1	55.85%
Gaze to correct monitor	κ=0.76	23.94%
TRJA	ICC=0.91	23.94%

III. Results

We analyzed the videos of the interaction with the robot and observed the parameters described in Section 2.3 for each participant. Overall, except for CH5 and CH11 (G1), all participants understood the matching game (i.e., choosing the same card as presented on the right or left monitor). All participants followed the prompt from the robot more than half of the time. As we were observing this particular behavior, we kept the data from the two children who did not understand the matching game.

A. *Observations*

In Table 3, we report the behavior of our participants during the matching game. We summarize in Table 4 the TRJA results of our participants. As shown in Table 3, participants from G2 and G3 responded well to joint attention when prompted by the robot. Except for CH9 (G2), none of them missed a prompt from the robot or looked at the wrong monitor. Participants from G1 showed more difficulty following the robot's movements. Participants from all of the groups, CH8 and CH10 (G1), CH9 (G2) and CH2 (G3), made mistakes choosing cards.

B. *Statistical Analysis*

A Kruskal-Wallis test was performed on the TRJA in regard to the movement of the robot (i.e., *Head Only*; *Arm Only*; *Head & Arm*) and the groups (i.e., G1; G2; G3). Indeed, we determined with a one-sample Kolmogorov-Smirnov test that the dependent variables (TRJA) were not normally distributed, and we worked with more than two independent groups. A post-hoc test was performed with the Wilcoxon Rank Sum test for pairwise comparisons.

A significant difference in TRJA for the entire experiment between the three groups was found ($\chi^2(2)=37.25$; $p<0.001$), see Figure 6. There were significant differences between G1 and G2 ($Z=-5.90$; $p<0.001$) and between G1 and G3 ($Z=-3.45$; $p<0.001$), for the totality of the experiment. Weak evidence for a difference in TRJA between G2 and G3 was found ($Z=1.82$; $0.05<p<0.1$) for the totality of the experiment. G1 had the slowest response to the RJA (M=4.90, SD=4.65), followed by G3 (M=2.67, SD=1.46) and G2 was the fastest (M=2.21, SD=1.41).

A significant difference in TRJA for the *Head Only* condition between the three groups was found ($\chi^2(2)=18.47$; $p<0.001$), see Figure 6. A significant difference between G1 and G2 ($Z=-7.18$; $p<0.001$) and moderate evidence for a difference between G1 and G3 ($Z=-2.10$; $0.01<p<0.05$) in *Head Only* condition were found. G1 had the slowest response to the RJA in *Head Only* condition (M=5.04, SD=4.13), compared with G2 (M=1.81, SD=0.78) and G3 (M=2.68, SD=1.79).

A moderate difference in TRJA for the Arm Only condition between the three groups was found ($\chi^2(2)=7.48$;

0.01<p<0.05), see Figure 6. A significant difference in TRJA between G1 and G2 (Z=-2.64; p<0.01) for *Arm Only* condition was found. G1 had the slowest response to the RJA in *Arm Only* condition (M=4.20, SD=3.96), compared with G2 (M=2.29, SD=1.01) and G3 (M=2.80, SD=0.99).

A significant difference in TRJA for the *Head & Arm* condition between the three groups was found ($\chi^2(2)=13.44$; $p<0.01$), see Figure 6. Significant differences between G1 and G2 (Z=3.34; p<0.001) and between G1 and G3 (Z=-2.66; p<0.01) were found in *Head & Arm* condition. G1 had the slowest response to the RJA in *Head & Arm* condition (M=5.42, SD=5.89), compared with G2 (M=2.54, SD=2.05) and G3 (M=2.51, SD=1.61).

TABLE 2. PARTICIPANTS' DESCRIPTION

G#	ID#	Gender	Age	Comments
G1	CH3	M	12	-
	CH5	F	11	Non-verbal; West Syndrome (uncommon-to-rare epileptic disorder [33]).
	CH8	M	15	-
	CH10	M	10	-
	CH11	M	17	Non-verbal
G2	CH1	M	11	-
	CH4	M	13	High level of cognition. Asked to be part of the program to meet Nao.
	CH7	M	8	-
	CH9	F	12	-
G3	CH2	M	9	Suffers from echolalia
	CH6	M	13	-

TABLE 3. BEHAVIOR OF THE PARTICIPANT DURING THE GAME

G#	CH#	Missed prompt	Gaze to Wrong Monitor	Mistakes
G1	CH3	1	2	None
	CH5	1	0	No data
	CH8	6	0	Bear2 instead of Bear1 Bear3 instead of Bear1 Bike2 instead of Bike3
	CH10	0	1	Car2 instead of Car1
	CH11	2	2	No data
G2	CH1	0	0	None
	CH4	0	0	None
	CH7	0	0	None
	CH9	2	0	Bike2 instead of Bike3
G3	CH2	0	0	Tree3 instead of Tree2
	CH6	0	0	None

TABLE 4. MEAN TIME OF RESPONSE TO JOINT ATTENTION

The mean TRJA for each condition (i.e., *Head Only*, *Arm Only* and *Head & Arm*) and for the whole interaction (Total) are presented.

G#	CH#	Head (s)	Arm (s)	Head & Arm (s)	Total (s)
G1	CH3	5.42 ± 3.29	2.78 ± 0.51	5.43 ± 4.93	4.48 ± 3.28
	CH5	2.53 ± 0.40	2.29 ± 0.42	3.59 ± 1.47	2.88 ± 1.08
	CH8	4.05 ± 1.71	9.82 ±10.2	5.43 ± 3.91	5.62 ± 4.66
	CH10	2.5 ± 0.15	2.93 ± 0.96	2.53 ± 0.22	2.65 ± 0.57
	CH11	12.13 ±4.72	5.8 ± 4.56	13.2 ±12.3	9.77 ± 7.33
G2	CH1	2.23 ± 0.47	2.93 ± 0.52	4.35 ± 3.54	3.17 ± 2.13
	CH4	1.23 ± 0.24	1.55 ± 0.30	1.39 ± 0.36	1.39 ± 0.31
	CH7	1.13 ± 0.6	1.80 ± 0.71	1.67 ± 0.69	1.53 ± 0.69
	CH9	2.65 ± 0.4	3.03 ± 1.51	2.74 ± 0.43	2.79 ± 0.81
G3	CH2	2.07 ± 0.46	2.10 ± 0.42	1.59 ± 0.67	1.92 ± 0.55
	CH6	3.29 ± 2.47	3.51 ± 0.88	3.43 ± 1.81	3.41 ± 1.70

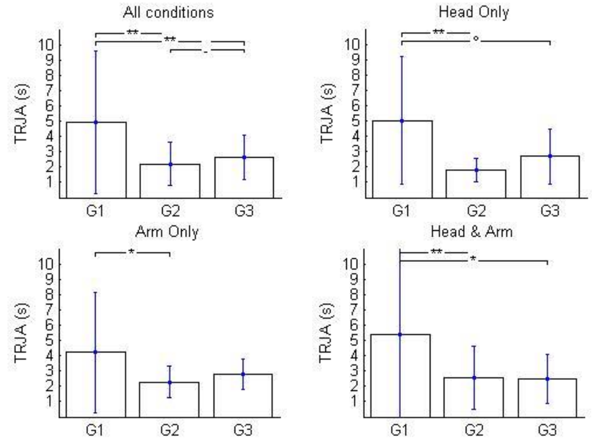

Figure 6 Time of Response to joint attention of each group for the whole experiment (top-left), *Head Only* condition (top-right), *Arm Only* condition (bottom-left) and *Head & Arm* condition (bottom-right).
- 0.05<p<0.1; ° 0.01<p<0.05; * p<0.01; ** p<0.001

We found no significant difference in TRJA between the conditions (*i.e., Head Only; Arm Only; Head & Arm*) intra-groups.

IV. Conclusion and Discussion

In this paper, we described the design of a Joint Attention interaction task (a matching game) with the Nao robot for individuals with ASD. In our previous work [19], we presented a way to define individual profiles by looking at the integration of proprioceptive and visual cues of an individual and linking it to his/her social and communication skills. In this paper, we aimed to show the link between these profiles and the behaviors of the participants during the matching game with Nao. We found that participants with an overreliance on proprioceptive cues and with a hyporeactivity to visual cues showed different behavior in their response to joint attention elicitation. As expected, they were slower at following the prompt of the Nao robot than participants with an overreliance on visual cues and with a hyporeactivity to proprioceptive cues. This allows us to validate our hypotheses H2A and H2B. In addition, the most proprioceptive group (G1) had a slower TRJA than G2 for each condition (i.e., *Head Only*; *Arm Only*; *Head & Arm*) and slower than G3 for the *Head Only* and *Head & Arm* conditions. This goes in the direction of our hypothesis H3, stating that individuals with an overreliance on visual cues should react more easily to the prompting of the robot, regardless of the level of prompting. Mistakes were made by four participants from the three groups. These results do not permit us to validate H4. A prior experiment using a short interaction with a robot [19] concurred with our findings. Participants with a hyporeactivity to proprioceptive cues and with an overreliance on visual cues had more successful interactions than participants with an overreliance on proprioceptive input and hyporeactivity to visual cues.

In [9], the authors showed that the greater the reliance on proprioception, the greater the child's impairments in social function and imitation. They suggested a greater-than-normal dependence on cortical regions in which movements are represented by intrinsic coordinates of motion (M1 and somatosensory cortex) and a less-than-normal dependence on regions in which movements are represented by extrinsic coordinates (premotor and posterior parietal) in children with ASD. The parietal and superior temporal cortices support the response to joint attention development in infancy [13]. They serve aspects of representational development, imitation, and the perception of the eye and head orientations of others, as well as the perception of spatial relations between the self, other, and the environment. Our results showed that participants with greater reliance on proprioception showed slower response to joint attention, confirming the results in [9]. In [24], the authors observed correlations between performance on the visual perception and pursuit tasks in children with ASD.

Our method for defining the individual profiles seems to be a promising approach since it enabled us to predict the behaviors displayed by our participants. Since each individual with autism needs a specific therapy, we think that this might be a relevant step towards designing individualized interactions.

The activity proposed was discussed prior to the experiment with the caregivers we work with, to be fitted for individuals with ASD. We also took inspiration from already existing setups for assessing Joint Attention (ESCS [23]). Unfortunately, even with these researches to avoid a too complicated or inappropriate task, two children did not understand the matching game.

A limitation of our work was the small number of participants (N=11). However, this is common in studies on ASD therapy with robots [25], and in the near future, we will work with eight new participants.

We used a Wizard of Oz setup because of the difficulty of tracking participants' faces. We did not want to use a wearable hat [16] or other invasive devices because we knew that most of our participants would not tolerate wearing them for an entire experiment.

ACKNOWLEDGMENTS

We thank the children for their participation, their families for accepting the participation of their children in our study, and the care centers' teams for their help.

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