Do Sensory Preferences of Children with Autism Impact an Imitation Task with a Robot?

Pauline Chevalier
Robotics & Computer Vision Lab, U2IS, ENSTA-ParisTech
828 boulevard des Maréchaux
Palaiseau, France
pauline.chevalier@ensta-paristech.fr

Gennaro Raiola
Robotics & Computer Vision Lab, U2IS, ENSTA-ParisTech
828 boulevard des Maréchaux
Palaiseau, France
gennaro.raiola@ensta-paristech.fr

Jean-Claude Martin
LIMSI, CNRS, Université Paris-Saclay
Bât 508, Campus Universitaire
Orsay, France
martin@limsi.fr

Brice Isableu
PSYCLE, Aix-Marseille Univ
Aix-en-Provence, France
brice.isableu@univ-amu.fr

Christophe Bazile
Groupement des Associations Partenaires de l'Action Sociale, France
cbazile@gapas.org

Adriana Tapus
Robotics & Computer Vision Lab, U2IS, ENSTA-ParisTech
828 boulevard des Maréchaux
Palaiseau, France
adriana.tapus@ensta-paristech.fr

ABSTRACT

Imitation is of major importance during social interactions, would it be between humans or between a human and a robot. This is even more true when considering users with special needs. In this paper, we describe an experimental imitation task protocol using a robot Nao that we designed to assess whether sensory profiles of children with Autistic Spectrum Disorder (ASD) influence their capabilities to imitate or to initiate gestures that are going to be imitated. We based our work on the hypothesis that children with an overreliance on proprioceptive cues and hyporeactivity to visual cues have a greater difficulty imitating and improve their skills more slowly than children with an overreliance on visual cues and hyporeactivity to proprioceptive cues. Twelve children and teenagers with ASD participated in seven imitation sessions over eight weeks. As expected, we observed that children with an overreliance on proprioceptive cues and hyporeactivity to visual cues had more difficulties imitating the robot than the other children. Moreover, the repeated sessions revealed to have positive effects on social behaviors displayed by all children (gaze to the partner, imitations) toward a human partner after the sessions with the robot. We conclude on the possible impacts of such results on the design of social human-robot interactions for users with ASD.

Keywords

Autism; Socially Assistive Robotics; Proprioception

HRI '17, March 06-09, 2017, Vienna, Austria
© 2017 ACM. ISBN 978-1-4503-4336-7/17/03…$15.00
DOI: http://dx.doi.org/10.1145/2909824.3020234

1. INTRODUCTION

Autism Spectrum Disorder (ASD) is the name for a group of developmental disorders that are characterized by deficits in communication and social skills and the presence of restricted and repetitive patterns of behaviors, interest or activities, as described in the DSM-V [1]. A great inter-individual variability is present in ASD: the symptoms of ASD fall on a continuum [1]. Some individuals can show much more severe symptoms than others. This inter-variability in ASD leads to a necessity to adapt and to personalize therapy for each individual.

Since individuals with ASD usually display a strong interest for computers, information and communication technologies have been used with participants with ASD (see [29] for a review). Research on Socially Assistive Robotics (SAR) for therapy for individuals with ASD is rapidly growing [18] and positive effects of robots on ASD participants have been observed [42, 16, 48, 41, 46, 10]. Although SAR features encouraging results for users with ASD, the individual differences are seldom considered.

We aim at investigating inter-individual differences between participants with ASD in order to design more adapted robot-based therapies for children with ASD. We consider proprioceptive and visual profiles [7] as an indicator of the social skills of our participants. We explain how we designed an experimental framework based on imitation of and by a robot. We describe the impact of our participants' individual profile on their behaviors during the imitation task. These results suggest that using an imitation task in human-robot interactions with children with ASD is especially useful for training social skills of children who have an overreliance on proprioceptive cues and hyporeactivity to visual cues. Sensory profiles could thus be used to guide the selection of social tasks that need to be trained for each individual user.

The remainder of the paper is organized as follows: Section 2 describes related work. Section 3 presents the methods used in this paper. Section 4 describes the design and the evaluation of the imitation task. Section 5 presents the results of the interaction between the robot and twelve children with ASD. Section 6 presents the paper's conclusions and a discussion of the results.

2. RELATED WORK

Motor, sensory, and visual processing impairments are present in autism and were taken into account recently with the publication of the DSM-V [1]. They have been outlined in SAR for ASD [20]. These deficits have an influence on the quality of life of individuals suffering from ASD and on their social development.

An overreliance on proprioceptive information is suggested in individuals with ASD [27, 28, 34, 24, 25, 30]. 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). It is derived from complex somatosensory signals provided to the brain by multiple muscle [26, 4, 44], joint [21], and skin receptors [17]. Individuals with ASD show normal to exacerbated integration of proprioceptive cues compared with typically developed (TD) individuals [27]. In [30], proprioceptive integration in ASD has been studied to gain a better knowledge of how these information influence social capacities. The authors observed that the greater the reliance on proprioception, the more children with ASD exhibited impairments in imitation and social interaction.

Moreover, individuals with ASD show impaired visual processing skills. Yet, vision is an important component of communication and social behaviors. As described in [45], the visual processing and gaze functions in individuals with ASD may lead to numerous impairments: unusual eye contact, difficulty following the gaze of others, difficulty supporting joint attention, and difficulty interpreting facial and bodily expressions of emotion.

We hypothesize that for our participants with ASD:

- (**H**) 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 with a robot.

To test our hypothesis, we needed a relevant task for the children to perform with the robot. Numerous studies observed the effects of a robot partner in imitation therapy for children with ASD [42, 16, 48, 41, 46, 10]. Indeed, imitation is described as one of the precursors of social cognition [37] and the dynamics of imitation (i.e., turn taking, initiation of new behaviors, and adaptation to other's behavior) are altered in the large majority of individuals with ASD [50, 5, 39]. But there is a substantial variability in imitation deficiencies in children with ASD: some children with ASD can learn or imitate spontaneously, while others have larger impairments [6]. A positive impact of imitation-based therapies on social skills was observed in children with ASD [12, 13, 40, 36, 22]. In [38], the authors found that there was a significant correlation between the level of imitation and level of imitation recognition in children with ASD. Some children with ASD recognized they were imitated. Those children showed different strategies to test the intentionality of their partners, such as: changing the rhythm of activity, changing the object used, and stopping the current action while gazing at the partner. Some children did not test their partners, but their attention increased and they showed more positive affects towards their partner. This may indicate that the children were aware they were being imitated without understanding the intentionality of the partner. These results underline the inter-variability of the symptoms in ASD, and the need to take them in account for therapy.

In SAR, the authors in [14] suggested that a task involving imitating robots could have a positive impact on individuals with ASD compared to a task involving imitating humans. Indeed, it was observed that children with ASD had impaired detection of biological motion compared to non-biological motion [33]. The authors in [42] observed in a longitudinal study with the Robota robot that social behaviors, such as gaze, touch, and imitation increased over time in children with ASD. In [16], the authors observed that the imitation of body movements and of familiar actions was higher when the children with ASD were paired with a human partner than with a robot partner. However, children with ASD who were paired with a robot showed increased shared attention and imitated facial expressions more than the children paired with a human partner. The authors in [48] observed the social engagement of four children with ASD and investigated whether they were more engaged with a Nao robot or with a human partner. There was a high variability in the reactions to the Nao robot. The robot did not impact the social engagement of two of the children. The other two displayed more gaze and smile/laughter behaviors with the robot compared to the human. One child performed better in the imitation task with Nao robot than with the human partner.

In the above studies, the authors described that SAR for training and learning imitation with individuals with ASD had a positive impact on their social skills. Training skills across several sessions is important in order to achieve a learning effect. Indeed, individuals with ASD show difficulties to learn new skills and to generalize them to new situations and new stimuli [23]. In addition, when evaluating SAR for individuals with ASD, it is important to verify if the skills learned with the robot are also applied later when interacting with a human partner [18, 47]. However, the authors in the above studies did not take in account any inter-individual variability.

In this paper, we propose to investigate inter-individual differences between participants with ASD. When individual differences between users with autism are considered, researchers consider mainly the cognitive level of the users. Here, we propose to compare our participants on their sensory profiles. We propose an imitation task with repeated sessions in order to observe the improvement and generalization of the acquired skills. To our knowledge, this is one of the first study to investigate proprioceptive and visual profiles for SAR for children with ASD.

3. METHODS

3.1 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 12 children with ASD (11.7±2.6 years old, two female participants) from these two care facilities. For confidentiality reasons, we coded the participants' identities as follows: CH#, with # from 1 to 12. From the care-centers, we recruited only participants who had an ASD diagnosis. Unfortunately, we did not have access to diagnostic reviews as ADOS-G, ADI-R or other ASD diagnostic assessments. Informed consent for participation was obtained from the parents. The experimental protocol was approved by the EA 4532 University local ethics committee.

3.2 Proprioceptive and Visual Preferences

The first step of our work was to define the profiles of our participants. As explained in Section 2, we aimed to identify if the integration of proprioceptive and visual cues impact the social and interaction skills of an individual with ASD. We used that we have developed in the past [7] to define each participant's profile. Our method is the combination of a well-known questionnaire: the Adolescents/Adults Sensory Profile (AASP) [3], and an experimental setup.

The AASP questionnaire assesses the individual's sensory processing preferences in terms of neurological thresholds for stimulation (high-low) and self-regulation strategies (active-passive) [15]. It has been already widely used in research for individuals with ASD [32, 19, 11]. It enables to collect an individual's movement, visual, touch, and auditory sensory processing preferences. The questionnaire was filled by the caregivers. Although we could have used the Sensory Profile questionnaire [15] which is dedicated to children, we decided to use the same AASP questionnaire that we used with adult participants in another study [7]. The caregivers who worked with us on this study estimated that the AASP questionnaire would also suit the children and teenagers from their care-centers.

The experimental setup consists in the assessment with a force platform of: (1) the effect of a moving virtual visual scene on an individual's postural control and (2) the individuals' capability to use proprioceptive inputs provided in dynamics of balance to reduce visual dependency [2, 31]. To form the groups among the participants, a Clustering analysis (dendrogram, Ward method) was performed on the results of the AASP and the experimental setup data. The reader can find a full explanation of the setup in [7].

The resulting groups are as follows:

- Group G1, with the following children: CH3; CH5; CH8; CH10 and CH11; Participants in this group show an overreliance on proprioceptive cues and a hyporeactivity to visual cues;
- Group G2, with the following children: CH1; CH2; CH4; CH6; CH7; CH9; and CH12; Participants in this group show a hyporeactivity to proprioceptive cues and a overreliance on visual cues.

These two groups enabled us to analyse the imitation skills of our participants in regards to our hypothesis **H1**. Table 1 provides the participants personal information and their groups.

3.3 Current Work

In this paper, we present the design of an imitation experimental protocol for children with ASD. During the sessions, the children were instructed to imitate a partner, and were also imitated by the partner. With the imitation task, we aimed to validate the relevance of the proprioceptive and visual individual profiles we defined in the previous Section as

Table 1: Participants' personal information

G#	ID#	Gender	Age	Comments
G1	CH3	M	12	-
	CH5	F	11	Low level of cognition; Non-verbal; West Syndrome (uncommon to rare epileptic disorder).
	CH8	M	15	-
	CH10	M	10	-
	CH11	M	17	Low level of cognition
G2	CH1	M	11	-
	CH4	M	13	High level of cognition. Asked to be part of the program to meet the Nao robot.
	CH6	M	13	-
	CH9	F	12	-
	CH12	M	9	-
	CH2	M	9	Suffers of echolalia
	CH7	M	8	-

a prerequisite for maximizing the robot influence (usability) on facilitating imitation and improving social interaction. We sought to validate our hypothesis **H**. More precisely, we hypothesized that:
An individual with an overreliance on proprioceptive cues and a hyporeactivity to visual cues would:

- **(HA)** struggle more to imitate his/her partner;
- **(HB)** struggle more initiating movements for his/her partner to imitate him/her;
- **(HC)** have slower improvements in his/her imitation skills across the sessions;

than an individual with a hyporeactivity to proprioceptive cues and a overreliance on visual cues.

4. DESIGN OF THE IMITATION TASK

4.1 Content of the Interaction

With the help of the caregivers from our partner facilities, we designed an imitation task with a robot. We wanted in this experiment to observe the effect of training session on imitation skills, and the generalization on a human partner. So as, the participants interacted with a human partner and a robot (Nao, from SoftBank robotics, formally Aldebaran). The children knew the human partner but had never worked with her in therapeutic sessions. As the authors in [35] observed that children who saw the robot act in a social-communicative way were more likely to follow its gaze than those who did not, and to remove fear or reluctance towards the robot, the Nao robot was presented to the children before this experiment [7]. As all of the children met the robot before, and knew the experimenter, there were no expected novelty effects in any of the partners (human or robot). The sessions were organized identically for all participants, as described in Table 2. There was seven sessions for each participant. Each session had a code name: H# for a session with

Table 2: Planning of the experimental protocol. Sessions are coded as follow: H# for a session with a human partner, and R# for a session with Nao robot as partner, with # from 0 to 6 for each number of sessions.

Week	Session code	Session purpose	Session partner
Week 0	H0	Baseline	Human
Weeks 1	R1	Baseline	Robot
Weeks 2 to 4	Training	R1-R4	Robot
Week 5	Break	-	-
Week 6	H5	Post-test	Human
Week 7	R6	Post-test	Robot

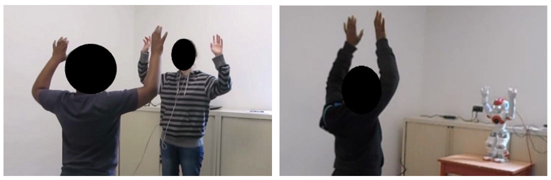


Figure 1: Pictures of the setup with the human partner (left) and robot partner (right)

a human partner, and R# for a session with Nao as partner, with # from 0 to 6 for each number of sessions. The first and 5th sessions (H0 and H5) were with the human partner, and the other ones (R1, R2, R3, R4 and R6) with the robot partner. The sessions H0 and R1 were baseline sessions, enabling us to observe the skills of the children with both of the partner before the training sessions. Sessions R2 to R4 were the repeated sessions for training the imitation skills. After session R4, we observed a break of one week. Then, the 6th and 7th sessions (H5 and R6) were post-test sessions, enabling us to observe if there were generalization effects on the imitation skills of the participants.

The sessions were held in a reserved room in each of the care centers. The children were in front of the partner. When the session was with the robot, the robot was placed on a table, due to the small size of the Nao robot. An Xtion RGB-D camera was fixed in front of the child, and 2 cameras recorded the sessions. The child could sit or stand in front of the partner. Figure 1 shows the setup for both partners. There are two phases in each session: (a) the child imitates the partner (human/robot) and (b) the partner (human/robot) imitates the child.

4.1.1 Phase (a): the child imitates the partner

In this phase, the child has to imitate the arms movements of the partner (human or robot). Several imitation tasks have been proposed in other studies for example involving objects [37]. We decided to define a simple gesture imitation since these motor tasks may be impacted by visual and proprioceptive preferences and because of the limitations of the embodiment of the robot Nao. The protocol was design with the help of the caregivers from the care-facilities in regards of their work with the children with ASD.

To keep the attention of the participants and make the interaction meaningful, we designed it as a playful task. The partner was initiating arms movements on a song, as she/it was dancing. As we work with children with a wide range of cognition levels and motor skills, the songs lacked lyrics and the gestures were limited to the arm gestures. Each movement is a combination of the left and right arms (L and R, respectively) taking one of the following five positions: D: down; U: up; F: in front; P: in ψ; and T: in T form, see Figure 2. The movements to imitate were randomly ordered to avoid a learning effect between the repetitions. For the human partner, the movements were chosen in real time, and for the robot partner, the list of movements was computed at the beginning of a dance.

We used three songs, with the same rhythms and durations (1 min 30 s). During a session, two of the three songs were used. In this way, we hoped to keep the children interested, as well as to be able to alternate the songs between the sessions. A song is played a maximum of two times in a session. In ASD, unusual responses to sensory stimuli have been observed [43]. To prevent unexpected behaviors toward the songs, we asked to the caregiver for each child if they tolerated and liked music, and we had the possibility to lower or turn off the music if needed. Overall, the children liked the music. The child imitated the partner a maximum of four times by session (in total, six minutes of imitation). Participants were able to take short breaks, if needed, between the dances.

We wished to propose sessions that adapt to each participant, stimulating and evolving in time. To avoid boredom across the sessions, the number of arms gestures increased throughout the sessions in an adaptive manner i.e., related to 80% of gestures correctly imitated (see Table 3 to see the movements that were imitated during a specific session). The number of correct movement was annotated by the experimenter while the child was performing the imitation. The time between the movements was modulated by the performance of the child during a dance within a session. In a session, if a participant performed 80% of the movements in two consecutive dances, the time between two movements decreased in the next dance. If the child was unable to imitate 80% of the movements the time between two movements was unchanged. The time between two movements was 8 seconds and could decrease to 6, 4, and 2 seconds, depending on the participant's performance. The time between two movements were discussed with the caregivers. The first sessions started with a movement every 8 seconds, to enable the caregivers to have enough time to correct and encourage the children to imitate the partner. It was also short enough not to lose the attention of the children. The decreases were chosen to gradually increase the attention of the children towards the partner. In sessions H0 and R1, the partner produced a movement every 8 seconds. At the beginning of the R2 to R4 sessions, the time between two movements was set as the one reached at the last dance of the previous session. In the H5 and R6 sessions, the partner started the session with the frequency reached in the session R4. If a participant reached the level of a movement every 2 seconds, the first dance was reset to a movement every 4 seconds in the next session. Indeed, to follow this frequency of a movement every 2 seconds was quite demanding to maintain for 4 dances. Finally, if the participant imitated 80% of the movements, the partner cheered for the child at the end of a repetition. During this phase, the caregiver was next to the child and was asked to help him/her understand the imitation task, encourage the child to imitate the partner and correct his/her arms position, if needed.

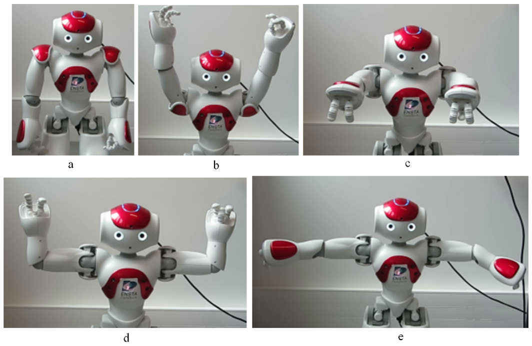


Figure 2: Example of the arm positions for Nao: a: LDRD; b: LURU; c: LFRF; d: LPRP; and e: LTRT

Table 3: Arm positions for the partner. Each movement is a combination of the left and the right arm (L and R, respectively) taking one of the following five positions: D: down; U: up; F: in front; P: in ψ; T: in T form

Session code	Movements
H0-R1	M1 = LDRD + LURU + LFRF + LPRP + LTRT
R2	M2 = M1 + LURP + LPRU + LTRF + LFRT
R3	M3 = M2 + LURD + LDRU + LTRP + LPRT
R4-H5-R6	M4 = M3 + LFRP + LPRF + LTRU + LURT

4.1.2 Phase (b): the partner imitates the child

In this phase, the partner imitated the gross arm movements of the child. The child was told to do slow large arms movements. A different song of 1 m 30 s was played during this phase. It permitted to link between the Phases (a) and (b). In addition, we hoped it will encourage the child to perform movements, and it gave a time limit to this task. In the care facilities we work with, the children work mostly with a timer. During this phase, the caregiver remained with the child and tried to encourage him/her to perform arms movements.

4.1.3 Observed behaviors

The sessions were recorded and the behavior of the participants was manually annotated. In both phases, we observed the participants' *percentages of gaze* to the human/robot and *percentages of smiles* during the interaction. In addition, in Phase (a), we observed the *imitation score* was assessed; in Phase (b), the *free initiations* were noted. Imitation scores were annotated as follows: "0" if there was no movement, if there was a movement that appeared to be random or not connected to the movement of the partner or incorrect; and "1" if the movement was correctly imitated. Then, we computed the percentage of the movement that was correctly imitated. As described in Section 4.1.1, the number of movements increased if the child correctly imitated the partner. We defined the *number of movements* the children imitated as an indicator of the improvement and success of a child to imitate the partner. Free initiation is the percentage of the time during which the child initiates movements for the partner to imitate him/her during Phase (b).

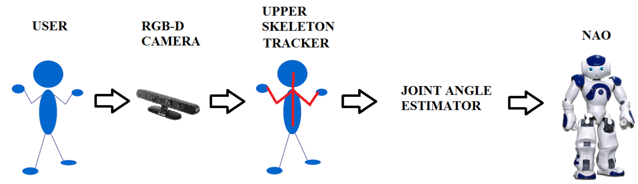


Figure 3: Schematics of the imitation system

4.2 System Design

4.2.1 Phase (a)

We used API Naoqi[1] provided by Softbank Robotics to program the gestures for imitating Nao. The experimenter launched the program when the child was ready and in position in front of the robot. The song and gestures started together. The experimenter could stop the song and gestures at any moment.

4.2.2 Phase (b)

We used a RGB-D camera (Xtion Asus[2]) and the ROS package Openni2_tracker[3] to track the participants' upper body. The tracker provides the skeleton of the user, which is a list of body joints. These joints are translated into the motor commands for the Nao robot through a joint angle estimator and Naoqi. The joint angle estimator converts the shoulder and elbow angles from the participant into scaled angles for Nao. See in Figure 3 a schematic of the system. The participants could stay seated and no calibration-pose was needed to start the imitation by the robot. A similar system has been used successfully in previous studies [48].

4.3 Data Analysis

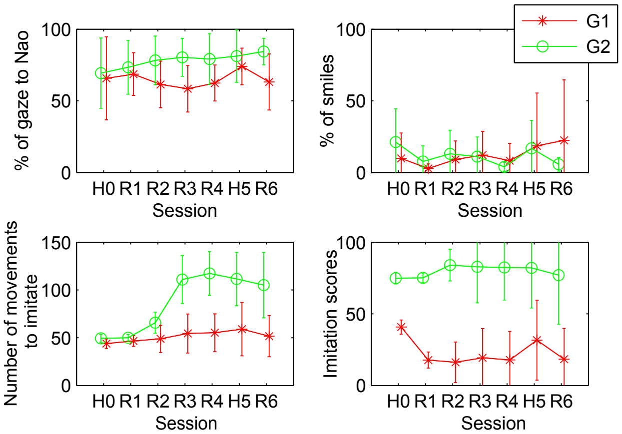
In total, each participant performed 7 sessions of approximately 10 minutes, interacting with the partner (human and robot), resulting in 84 videos. A first coder annotated all videos and a second coder, unaware of the hypotheses of the setup, annotated 20% of the videos, which were randomly chosen. An intraclass correlation coefficient (ICC) was computed to assess the inter-coder reliability. The ICC was 0.86, which shows good inter-coder reliability. We observed the effect of the groups on the participants' gaze direction, imitation scores, free initiation, and smiles as explained in Section 4.1.3. We performed a repeated-measure ANOVA on participants' behaviors. Post-hoc analyses were performed with Tuckey's HSD test.

5. RESULTS

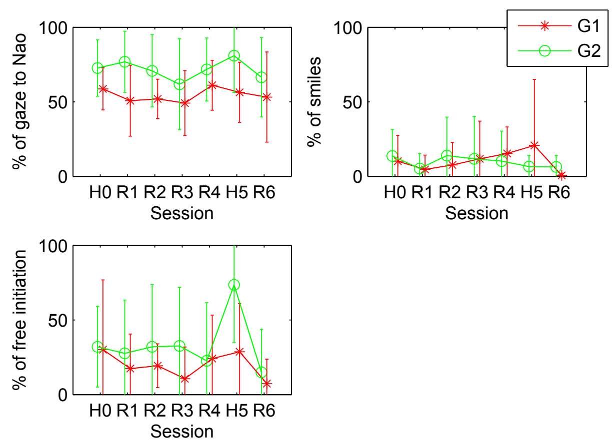
All 12 children performed all seven sessions of the experiment. They were enthusiastic to participate in the sessions, even the children who did not perform well on the task. A child, CH2 (G3), was very agitated and perturbed for the final four sessions (out of seven sessions) due to personal issues. We did not include him in the statistical analysis of the proprioceptive and visual profiles because his behavior

[1] http://doc.aldebaran.com/2-1/naoqi/
[2] https://www.asus.com/fr/3D-Sensor/Xtion_PRO/
[3] https://github.com/ros-drivers/openni2_tracker

changed significantly. As for all the other participants, we still describe his behavior.



(a) Phase (a)



(b) Phase (b)

Figure 4: Observed behaviors by groups G1 and G2 through the sessions in Phases (a) and (b). H# for a session with a human partner, and R# for a session with Nao as partner, with # from 0 to 6 for each number of sessions.

5.1 Phase (a)

In this phase, children had to imitate the partner. Figure 4a show the observed behaviors for the G1 and G2 groups in Phase (a).

Gaze to the partner.

We observed a weak significant main effect of the groups on the gaze direction of the children during Phase (a) ($F(1, 9) = 4.21$; $0.05 < p < 0.1$). Participants from G1 looked globally less to the partner than the participants from group G2 (G1: $M = 64.83$, $SD = 17.13$; G2: $M = 78.02$, $SD = 16.89$). We observe in Figure 4a an increase in the mean gaze to the partner, through the session for group G2, indicating that the repeated sessions helped the children from group G2 to look more at their partners. We do not observe an increase on the participants from group G1 (Figure 4a). However, the participants from group G1 seemed to look more at the partner in session H5 than in the other sessions, even if this result is not significant. This may indicate that the repeated sessions with the robot helped those children to look more at a human partner.

Smiles.

No effect of the groups was found on the smiling behavior of the children.

Number of movements for the children to imitate.

We found a significant main effect of the groups on the number of the imitated movements ($F(1, 9) = 34.94$; $p < 0.01$). Children from group G1 produce fewer imitation movements than the children from group G2 (G1: $M = 51.34$, $SD = 17.25$; G2: $M = 87.14$, $SD = 35.04$). This indicates that children from group G2 improved faster than children from group G1. Both groups had an increase in their number of movements.

Imitation scores.

We found a significant main effect of the scores on the groups ($F(1, 9) = 17.65$; $p < 0.01$). Children from group G2 were more successful than children from group G1 (G1: $M = 23.09$, $SD = 26.81$; G2: $M = 79.79$, $SD = 20.25$). In Figure 4a, even if this result is not significant, we can observe that the children from G1 seemed to have a higher score in the sessions with the human partner, which is different from the children in group G2.

5.2 Phase (b)

In this phase, the partner had to imitate the arm movements of the child. Figure 4b shows the observed behaviors for the G1 and G2 groups in Phase (b). The participants from G1 had more difficulties understanding that they had to produce movements regardless of those of the partner, and that the robot was imitating them. When the session was with the robot, they often imitated the robot instead of initiating movements. Indeed, the robot was slightly moving from the noise based on skeleton data form the RGB-D camera and some children were reproducing the slight movements of the robot.

Gaze to the partner.

We observed a weak significant effect of the groups on the gaze direction of the children during Phase (b) ($F(1, 5) = 5.46$; $0.05 < p < 0.1$). Participants from G1 looked globally less often to the robot than the participants from group G2 (G1: $M = 54.46$, $SD = 4.39$; G2: $M = 71.60$, $SD = 6.31$).

Smiles.

No effect of the groups was found on the smiling behavior of children. In Figure 4b children in group G1 smiled less in the last session of the therapy than in the other sessions.

Free initiation.

Free initiation was not significantly different between the groups on the whole experiment ($F(1, 5) = 0.08$; $p = ns$). In Figure 4b, we can observe that in H5, the free initiation increased in both groups G1 and G2, and more drastically in G2 than in G1.

5.3 Observed behaviors

We describe here the behaviors of the participants during the sessions.

CH3 (G1) was very enthusiastic to play with the robot and really appreciated the songs. In Phase (a), we observed an improvement of the gaze for the human partner after the sessions with the robot. He looked the human partner more successfully after the sessions with the robot. Indeed, in session H0, he gazed 80.52% of the time to the human, and 94.64% in session H5 after the four sessions with the robot partner and the week-long break. The number of movement to imitate increased with the sessions, indicating an improvement in the imitation. In Phase (b), the child was moving his arms to make the partner move, but he was not looking at the partner most of the time. Instead, he was closing his eyes or putting the head down.

CH5 (G1) had troubles understanding the tasks in Phases (a) and (b). In Phase (a), she gazed at her partner approximately 76% of the time. She imitated the human partner better than the robot partner. In Phase (b), it was very difficult to keep her focused on the task.

CH8 (G1) had difficulties understanding the imitation and initiation tasks in both Phases (a, b). However, his caregiver said he liked the sessions because he was not reluctant to come, and that he may have understood the task but was unwilling to perform the task.

CH10 (G1) performed the task but had some difficulties imitating the movement in Phase (a) (he was performing a random movement or always performing the same movement). At the end of each session with the robot, he kissed it on the head. The gaze behavior of this child did not improve with time in Phase (a); instead, it stayed stable. In Phase (b), the child initiated movements for a significant amount of time in sessions H5 and R6. He may have benefited from the repetitive sessions with the robot for this skill.

CH11 (G1) had difficulties understanding the imitation and initiation tasks. He performed evading gaze behavior. However, his gaze at the partner was higher after session H0 in Phase (a). He gazed more at the human partner after the session with the robot. In H0, he looked at the partner 14.10% of the time, which was 60.72% in H5. By contrast, in Phase (b), his gaze increased from H0 to R4 and decreased with the human partner in H5.

CH1 (G2) was very enthusiastic about participating to the sessions. He even ran to the experiment room. In Phase (a), his gaze to the partner was good and constant over the time. He always succeeded with the imitation task and was able to follow the robot movement when the gestures were every 2 seconds. The number of movement to imitate increased with the sessions, indicating an improvement in the imitation. In Phase (b), his gaze to the robot decreased in the last session. Free initiation was higher in session H5 than in the other sessions.

CH4 (G2) expressed some reluctance to participate in the sessions and most of the time he asked to perform only two to three dances with the robot. However, his gaze on the partner was good and constant over the time. He always succeeded in the imitation task and he was able to follow the robot movement when the gestures were every 2 seconds. In Phase (b), the child did not want to initiate movement with the human partner in the first session H0, but he accepted the participation conditions during the remainder of the experiment. He initiated movement with the robot and tested the behavior of the robot. During session H5, he seemed to enjoy initiating movements with the human partner, and smiled more during this session.

CH7 (G2) was enthusiastic about performing the task at the beginning of a session and then showed signs of boredom from the middle to end of sessions. We observed that this participant increased his gaze on the partner in Phase (a). The number of movement to imitate increased with the sessions, indicating an improvement in the imitation. In Phase (b), with the robot partner, he did not understand he was imitated. He was imitating the robot movement. The percentage of free initiation was higher with the human partner ($M = 67.35$; $SD = 3.51$) than with the robot partner ($M = 9.81$; $SD = 11.80$), and no improvements were visible from H0 to H5 sessions. However, the child looked more at session H5 (70.86%) than at session H0 (63.85%).

In Phase (a), CH9 (G2) showed an improvement in her gazing behavior to the partner throughout the experiment. She also improved her imitation skills by being more focused on the partner. Indeed, she looked more at her caregiver than at the partner and was not focused on the task at all. We observed that this participant increased his gaze on the partner in Phase (a). The number of movement to imitate increased with the sessions, indicating an improvement in the imitation. She succeeded in reaching the level at which were the partner was moving every 2 seconds. In Phase (b), she did not initiate the partner except in session H5. She may have benefited from the repetitive sessions with the robot for this skill.

CH12 (G2) was enthusiastic to participate in the sessions. He understood the tasks. In Phase (a), we observed that his gaze towards the partner increased through the sessions. The gaze on the human after the sessions with Nao robot was higher compared to during the first session. The number of movement to imitate increased with the sessions, indicating an improvement in the imitation. He succeeded in performing the imitation task and was able to follow the robot movement when the gestures occurred every 2 seconds. In Phase (b), except in session R1, the participant focused his attention on the partner. The gaze percentage increased over time. In session H5, he was really enthusiastic to initiate movement in the human partner and asked to repeat the task several time.

As mentioned before, CH2 (G3) was very agitated and perturbed for the last four sessions due to personal issues. From H0 to R2, the gaze to the partner of the child increased and then decreased for Phase (a). In Phase (b), he was quite agitated and it was difficult to get the robot to imitate him.

CH6 (G3) was very enthusiastic about participating in the sessions. He even ran to the experiment room and asked if he was going to see the robot when he saw the experimenter in the care center. In Phases (a) and (b), his gaze on the partner was good and constant over time. He always succeeded in performing the imitation task and was able to follow the robot movement when the gestures were every 2 seconds. The number of movement to imitate increased with the sessions, indicating an improvement in the imitation. In Phase (b), his gaze on the robot decreased in the last session. He had few difficulties understanding Phase (b) with the robot partner. He imitated the robot in the beginning, but after a few trials, he understood the task and initiated movement for the robot.

6. CONCLUSIONS AND DISCUSSION

In this paper, we explain how we developed a robot-based imitation experimental protocol for children with ASD. We aimed to validate the relevance of the proprioceptive and visual individual profiles to design robot-based therapy for individuals with ASD.

We observed that participants who had hyporeactivity to visual motion and an overreliance on proprioceptive information (children from group G1) gazed less towards their partner than participants who had an overreliance to visual motion and a hyporeactivity on proprioceptive information (children from group G2), during both phases of the sessions. Children from group G1 were less successful in imitating the partner than children from G2. Children from group G1 were less likely to initiate movement that could be imitated by the partner than children from group G2. Finally, children from group G1 had a slower improvement in their imitation skills than children from group G2.

As in the literature [42, 16, 48, 41, 46, 10], we observed positive effects of using a robot partner for individuals with ASD to improve imitation skills. We observed that children from group G2 gazed more to their partners through the sessions in Phase (a). The repeated interactions may have helped the children in both groups to look more at the human partner, and children from group G2 to improve their will to initiate movements with a human partner. However, some children did not succeed in imitating the partner across the sessions or did not seem to understand that they were being imitated. The task may have been too complicated or inadequately adapted to them, and they might have needed more sessions to display real improvements of their imitation skills. For some children, Phase (b) was difficult to set-up, because they were unwilling to stand in front of the RGB-D camera for the time when they were correctly tracked, which might have contributed to their limited understanding of this phase. Overall, the repetitive sessions seemed to have a positive impact on the children's social skills for both groups G1 and G2. In addition, children seemed to enjoy the interactions: most of them showed enthusiasm when interacting with the robot. Overall, our results are in line with other results from similar studies showing the positive impact of imitation training for participants with autism. This supports that robot-based training of social skills for autistic users should feature an imitation task.

Whereas most studies with autistic users split the participants according to their cognitive level, we have split our group of users according to their sensory preferences. Our results suggest that this new way of splitting users with autism might be relevant for defining personalized protocols for training social skills and for designing associated multimodal human-robot interaction.

A main interest in SAR is to propose more autonomous robots, that will be able to adapt to the individual needs of children over longer periods of time [49]. Our results could help to design more adapted robot-based therapy for individuals with ASD as we observed that both groups had different gazing during the experimental protocol. Using users' gaze to predict the outcome of interactions with a robot could be a successful step to make robots more autonomous.

Taken together, with earlier assessments of our ASD population in other behavioral tasks [7, 9, 8] the present findings suggest that robot's cognitive architecture should integrate a module dedicated to online detection of sensory profiles, and then afford personalized scenario e.g., based on controlling the visual complexity of communication signals for training social skills in an optimal way.

Future works should focus on the design of more adapted tasks to all participants with a more autonomous robot-based system.

7. ACKNOWLEDGMENTS

We thank the children, their families, and the care centers' teams. This work is supported by Région Ile de France.

8. REFERENCES

[1] A. P. Association et al. *Diagnostic and statistical manual of mental disorders (DSM-5®).* American Psychiatric Pub, 2013.

[2] A. Bray, A. Subanandan, B. Isableu, T. Ohlmann, J. F. Golding, and M. A. Gresty. We are most aware of our place in the world when about to fall. *Current Biology*, 14(15):R609–R610, 2004.

[3] C. Brown and W. Dunn. *Adolescent-Adult Sensory Profile: User's Manual*. Therapy Skill Builders, 2002.

[4] D. Burke, K.-E. Hagbarth, L. Löfstedt, and B. G. Wallin. The responses of human muscle spindle endings to vibration of non-contracting muscles. *The Journal of physiology*, 261(3):673–693, 1976.

[5] M. Carpenter, M. Tomasello, and T. Striano. Role reversal imitation and language in typically developing infants and children with autism. *Infancy*, 8(3):253–278, 2005.

[6] T. Charman and S. Baron-Cohen. Another look at imitation in autism. *Development and psychopathology*, 6(03):403–413, 1994.

[7] P. Chevalier, B. Isableu, J.-C. Martin, and A. Tapus. Individuals with autism: Analysis of the first interaction with nao robot based on their proprioceptive and kinematic profiles. *Advances in Robot Design and Intelligent Control*, pages 225–233, 2015.

[8] P. Chevalier, J.-C. Martin, B. Isableu, C. Bazile, D.-O. Iacob, and A. Tapus. Joint attention using human-robot interaction: Impact of sensory preferences of children with autism, to appear. *RO-MAN 2016*, 2016.

[9] P. Chevalier, J.-C. Martin, B. Isableu, C. Bazile, and A. Tapus. Impact of sensory preferences of individuals with autism on the recognition of emotions expressed by two robots, an avatar, and a human. *Autonomous Robots*, pages 1–23, 2016.

[10] D. Conti, S. Di Nuovo, S. Buono, G. Trubia, and A. Di Nuovo. Use of robotics to stimulate imitation in children with autism spectrum disorder: A pilot study in a clinical setting. In *Robot and Human Interactive Communication (RO-MAN), 2015 24th IEEE International Symposium on*, pages 1–6. IEEE, 2015.

[11] L. Crane, L. Goddard, and L. Pring. Sensory processing in adults with autism spectrum disorders. *Autism*, 13(3):215–228, 2009.

[12] G. Dawson and A. Adams. Imitation and social responsiveness in autistic children. *Journal of abnormal child psychology*, 12(2):209–226, 1984.

[13] G. Dawson, D. Hill, A. Spencer, L. Galpert, and L. Watson. Affective exchanges between young autistic

children and their mothers. *Journal of abnormal child psychology*, 18(3):335–345, 1990.

[14] J. J. Diehl, L. M. Schmitt, M. Villano, and C. R. Crowell. The clinical use of robots for individuals with autism spectrum disorders: A critical review. *Research in autism spectrum disorders*, 6(1):249–262, 2012.

[15] W. Dunn. The sensory profile: UserâĂŹs manual (psychological corporation, san antonio, tx). 1999.

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

[17] B. B. Edin. Cutaneous afferents provide information about knee joint movements in humans. *The Journal of Physiology*, 531(1):289–297, 2001.

[18] D. Feil-Seifer and M. J. Mataric. Defining socially assistive robotics. In *Rehabilitation Robotics, 2005. ICORR 2005. 9th International Conference on*, pages 465–468. IEEE, 2005.

[19] H. Ferguson, B. S. Myles, and T. Hagiwara. Using a personal digital assistant to enhance the independence of an adolescent with asperger syndrome. *Education and Training in Developmental Disabilities*, pages 60–67, 2005.

[20] E. Ferrari, B. Robins, and K. Dautenhahn. Therapeutic and educational objectives in robot assisted play for children with autism. In *RO-MAN 2009-The 18th IEEE International Symposium on Robot and Human Interactive Communication*, pages 108–114. IEEE, 2009.

[21] W. Ferrell, S. Gandevia, and D. McCloskey. The role of joint receptors in human kinaesthesia when intramuscular receptors cannot contribute. *The Journal of physiology*, 386(1):63–71, 1987.

[22] T. Field, T. Field, C. Sanders, and J. Nadel. Children with autism display more social behaviors after repeated imitation sessions. *Autism*, 5(3):317–323, 2001.

[23] A. Froehlich, J. Anderson, E. Bigler, J. Miller, N. Lange, M. DuBray, J. Cooperrider, A. Cariello, J. Nielsen, and J. E. Lainhart. Intact prototype formation but impaired generalization in autism. *Research in autism spectrum disorders*, 6(2):921–930, 2012.

[24] B. Gepner, D. Mestre, G. Masson, and S. de Schonen. Postural effects of motion vision in young autistic children. *NeuroReport*, 6(8):1211–1214, 1995.

[25] B. Gepner and D. R. Mestre. Brief report: postural reactivity to fast visual motion differentiates autistic from children with asperger syndrome. *Journal of Autism and Developmental disorders*, 32(3):231–238, 2002.

[26] G. M. Goodwin, D. I. McCloskey, and P. B. Matthews. Proprioceptive illusions induced by muscle vibration: contribution by muscle spindles to perception? *Science*, 175(4028):1382–1384, 1972.

[27] E. Gowen and A. Hamilton. Motor abilities in autism: a review using a computational context. *Journal of autism and developmental disorders*, 43(2):323–344, 2013.

[28] S. Greffou, A. Bertone, E.-M. Hahler, J.-M. Hanssens, L. Mottron, and J. Faubert. Postural hypo-reactivity in autism is contingent on development and visual environment: a fully immersive virtual reality study. *Journal of autism and developmental disorders*, 42(6):961–970, 2012.

[29] C. Grossard and O. Grynszpan. Entraînement des compétences assistées par les technologies numériques dans lâĂŹautisme: une revue. *Enfance*, 2015(01):67–85, 2015.

[30] C. C. Haswell, J. Izawa, L. R. Dowell, S. H. Mostofsky, and R. Shadmehr. Representation of internal models of action in the autistic brain. *Nature neuroscience*, 12(8):970–972, 2009.

[31] B. Isableu, B. Fourre, N. Vuillerme, G. Giraudet, and M.-A. Amorim. Differential integration of visual and kinaesthetic signals to upright stance. *Experimental brain research*, 212(1):33–46, 2011.

[32] C. R. Jones, F. Happé, G. Baird, E. Simonoff, A. J. Marsden, J. Tregay, R. J. Phillips, U. Goswami, J. M. Thomson, and T. Charman. Auditory discrimination and auditory sensory behaviours in autism spectrum disorders. *Neuropsychologia*, 47(13):2850–2858, 2009.

[33] A. Klin, D. J. Lin, P. Gorrindo, G. Ramsay, and W. Jones. Two-year-olds with autism orient to non-social contingencies rather than biological motion. *Nature*, 459(7244):257–261, 2009.

[34] R. Kohen-Raz, F. R. Volkman, and D. J. Cohen. Postural control in children with autism. *Journal of Autism and Developmental Disorders*, 22(3):419–432, 1992.

[35] A. N. Meltzoff, R. Brooks, A. P. Shon, and R. P. Rao. âĂIJsocialâĂİ robots are psychological agents for infants: A test of gaze following. *Neural Networks*, 23(8):966–972, 2010.

[36] J. Nadel. *Imitation et communication entre jeunes enfants*, volume 13. Presses Universitaires de France-PUF, 1986.

[37] J. Nadel. Imitation and imitation recognition: Functional use in preverbal infants and nonverbal children with autism. *The imitative mind: Development, evolution, and brain bases*, pages 42–62, 2002.

[38] J. Nadel. Do children with autism understand imitation as intentional interaction? *Journal of Cognitive & Behavioral Psychotherapies*, 4(2), 2004.

[39] J. Nadel and G. Butterworth. *Imitation in infancy*, volume 16. Cambridge University Press Cambridge, 1999.

[40] J. Nadel-Brulfert and P. Baudonniere. The social function of reciprocal imitation in 2-year-old peers. *International Journal of Behavioral Development*, 5(1):95–109, 1982.

[41] I. Ranatunga, M. Beltran, N. A. Torres, N. Bugnariu, R. M. Patterson, C. Garver, and D. O. Popa. Human-robot upper body gesture imitation analysis for autism spectrum disorders. In *International Conference on Social Robotics*, pages 218–228. Springer, 2013.

[42] B. Robins, P. Dickerson, P. Stribling, and K. Dautenhahn. Robot-mediated joint attention in

children with autism: A case study in robot-human interaction. *Interaction studies*, 5(2):161–198, 2004.

[43] S. J. Rogers and S. Ozonoff. Annotation: What do we know about sensory dysfunction in autism? a critical review of the empirical evidence. *Journal of Child Psychology and Psychiatry*, 46(12):1255–1268, 2005.

[44] J. Roll and J. Vedel. Kinaesthetic role of muscle afferents in man, studied by tendon vibration and microneurography. *Experimental Brain Research*, 47(2):177–190, 1982.

[45] D. R. Simmons, A. E. Robertson, L. S. McKay, E. Toal, P. McAleer, and F. E. Pollick. Vision in autism spectrum disorders. *Vision research*, 49(22):2705–2739, 2009.

[46] A. Taheri, M. Alemi, A. Meghdari, H. Pouretemad, and S. Holderread. Clinical application of humanoid robots in playing imitation games for autistic children in iran. *Procedia-Social and Behavioral Sciences*, 176:898–906, 2015.

[47] A. Tapus, M. Mataric, and B. Scassellati. Attention to facial emotion expressions in children with autism. *IEEE Robotics and Automation Magazine (RAM), Special Issue on Grand Challenges in Robotics*, 14(1), 2007.

[48] A. Tapus, A. Peca, A. Aly, C. Pop, L. Jisa, S. Pintea, A. S. Rusu, and D. O. David. Children with autism social engagement in interaction with nao, an imitative robot–a series of single case experiments. *Interaction studies*, 13(3):315–347, 2012.

[49] S. Thill, C. A. Pop, T. Belpaeme, T. Ziemke, and B. Vanderborght. Robot-assisted therapy for autism spectrum disorders with (partially) autonomous control: Challenges and outlook. *Paladyn, Journal of Behavioral Robotics*, 3(4):209–217, 2012.

[50] M. Tomasello. *The cultural origins of human cognition*. Harvard university press, 2009.