“iCub says: Do my motor sounds disturb you?” Motor Sounds and Imitation with a Robot for Children with Autism Spectrum Disorder

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Abstract. In Socially Assistive Robotics, robots are used as social partners for children with Autism Spectrum Disorder. However, it is important to keep in mind that this population shows auditory hypo- or hypersensitivity, which results in avoiding or seeking behaviors towards sounds. Robots, from their mechanical embodiment, exhibit motor noises, and we aimed here to investigate their impact in two imitation games with iCub on a computer screen. We observed that participants who reported negative responses to unexpected loud noises were more able to focus on a “Simon says” game when the robot’s motor noises were canceled.

Keywords: Autism Spectrum Disorder; Socially Assistive Robotics; Imitation; Auditory sensitivity; Motor sounds.

1 Introduction

Robots have been found to be promising interaction partners for children diagnosed with Autism Spectrum Disorder (ASD), as their mechanical embodiment attracts children’s interest and the predictability of robot actions comforts the young patients [1], [2]. Robots have been used to train or evaluate social skills in children diagnosed with ASD with success, and many studies in Socially Assistive Robotics (SAR) focus on the use or the design of such robot interventions (see [3], [4] for general overviews of SAR for children diagnosed with ASD). However, individuals with ASD often show sensory hyper or hypo-sensitivity in addition to the social skills impairments, repetitive or stereotypical behaviors [5], [6]. Robots are a novel and complex source of sensory stimuli and their sensory information can be overwhelming for some children with ASD, rather than beneficial [7]. It is utterly important to investigate the noises produced by the robots’ body, for example from motors and fans, in SAR for children diagnosed with ASD,

Herein this study, we aimed to investigate if the response to a robot’s motors auditory signals in children diagnosed with ASD can be linked to their auditory sensory sensitivity, and if patterns of behaviors emerge. For example, a certain profile of participants might benefit, while others might be overwhelmed, by the motor sounds. As reducing or canceling the motor sounds from robots is a difficult task, given the current state of the motor technology and the available robots on the market, we aimed here to investigate their impact in socially assistive setups for children with ASD. This way, we can highlight and offer guidelines to design robot or robot interventions to minimize unwanted negative effects of the noise or to use the motor sounds as a tool to attract the attention of the participants, dependent on individual profiling.

To do so, we designed two imitation tasks with the robot iCub [8] presented on a computer screen. First, a simple imitation game in which the children had to imitate a set of five arm movements from the robot. Second, a "Simon says" game with the same set of arm movements. "Simon says"[1] is a game in which one of the players (here iCub) plays an instructor, and the other players (here the participants) play the followers. The instructor commands the followers to perform a movement with him, but only if the instructor pronounces the keywords "*Simon says*". This game enables to evaluate Executive Functions, i.e. the psychological processes involved in the conscious control of thought and actions, and more specifically Response Inhibition, i.e. the ability to inhibit learned behavioral responses to stimuli (here not to imitate the robot whereas the children are used to it) [9]. Both imitation and Executive Functions are impaired in autism ([5] and [10], respectively). We chose imitation tasks as they require movements from the robot, which enable us to expose our participants to motor noises. Imitation tasks have been already used in SAR for children with ASD [11]–[15]. We chose to present the robot on a screen instead of its real physical embodiment so we were able to manipulate the auditory cues from the motor more flexibly and in a more controlled manner.

2 Related Work

Sensory sensitivity plays a role in social interactions: social signals can come from the facial or bodily expression of emotions, from the tone of the voice, from the touch of someone's hand on the arm, etc. They are also present in human-robot interactions (HRI), as the robot needs to convey social signals in its behaviors, its voice, or its touch. However, contrary to humans, robots happen to have also motor noises. These noises have an impact on how robots are perceived. In [16] the authors observed that motor noises reduced the human-likeness of the robot, but sounds from motor of higher quality made the robot appear more competent. The motor noises also have impact on the performance of the participants when performing movements in synchronization with robots. In [17], the authors asked participants to wave their arm with a Pepper robot in various auditory and visual conditions. They observed that participants' performance was impaired in the waving task when exposed to the actuator noises while observing the robot waving. Motor noises can also drive design choices in HRI. For example, when the robots need to give instructions to the user, some studies made the robot talk

[1] https://en.wikipedia.org/wiki/Simon_Says

and move successively, to be sure the robots' body noises do not interfere with the understanding of the instructions.

In SAR for children diagnosed with ASD, the impact of the robot's motor noises takes another dimension as children diagnosed with ASD show sensory hypo- or hypersensitivity [1], [2]. The effect of noises can be overwhelming for some individuals, which can results in such behaviors as covering the ears to reduce the unpleasant sounds. For others, however, the noise can be appealing or stimulating [6], [18]. Previous works observed the impact of sensory sensitivity in children diagnosed with ASD in HRI [12], [19], [20]. These works reported that visual and proprioceptive sensitivity influenced the children with ASD behaviors and performances in a social task with a robot. However, to our knowledge, no previous work investigated the impact of auditory sensitivity in socially assistive robotics for children with ASD.

3 Methods

3.1 Participants

We recruited 21 children diagnosed with ASD at the Piccolo Cottolengo Genovese di Don Orione (Genoa, Italy). Diagnosis of ASD was confirmed by the healthcare professionals of the institute, using the ADOS screening tool [21]. Parents or legal tutors provided a signed written informed consent. Our experimental protocols followed the ethical standards laid down in the Declaration of Helsinki and were approved by the local Ethics Committee (Comitato Etico Regione Liguria). Participants were already experienced in interactions with robots. They all interacted with Cozmo (Anki Robotics) and iCub [8] in previous experiments that took place within the joint collaborative project between Istituto Italiano di Tecnologia and Don Orione Italia. Three participants were excluded from the experiment because screening data was not filled by the parents, one because of a technical error, and other three as they did not succeed in finishing one or both sessions. The data of 14 participants (age = 6.6 ± 0.9 years old, 2 females) were subject to analysis. The participants' demographics can be found in Table 1.

Table 1. The 14 participants' demographics, IQ and ADOS levels

Sex	**Age**	**IQ**	**ADOS**
M=12, F=2	6.6 ± 0.9 years old	75.786 ± 15.547	**1**: N=8; **2**: N=5; **3**: N=1

3.2 Development of the experimental setup

As we aimed to understand the impact of the robot's motor noises, we chose to use a monitor-based study. Presenting stimuli on a computer screen allowed us to remove or present the motor noises to the participants flexibly, without the use of a canceling-noise headsets or earplugs. We developed the imitation and "Simon says" tasks on Psychopy v2021.1.4 [22]. As stimuli material, we recorded a video of the robot iCub performing a set of five arm movements and a neutral pose (see Figure 1) and recorded the sentences it was going to pronounce during the experiment by means of the Text-To-

Speech SVOXPICO[2] in Italian. The audio track of the video was modified in Audacity 2.4.2 to attenuate the robot's fans noises present in the recordings. We normalized the audio track and then performed a noise reduction (parameters of the reduction: noise reduction: 12dB, sensitivity 2.00, and frequency smoothing: 5bands). Then, we sliced the video to obtain single videos for each movement for the imitation and "Simon says" games and for the neutral posture the robot takes when idle or talking. The audio tracks of each movement can be seen in Figure 1. During the experiment, the audio output (robot's voice and motor noises) was fixed around 70dB, which is the decibel level of a normal conversation.

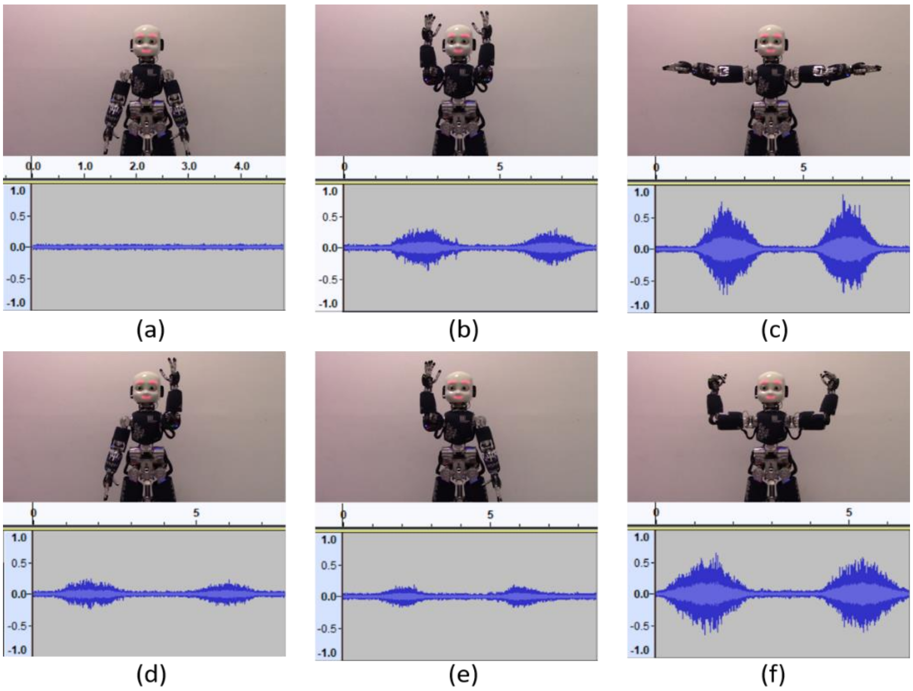

Fig. 1. Positions and soundtracks taken by the robot in the imitation and "Simon says" games. (a) neutral position; (b) arms up; (c) arms in "T"; (d) right arm up; (e) left arm up; and (f) arms as if the robot was showing its biceps. All movements start from the neutral position, go to the apex of the movement and stays in it for 2 seconds, and return to the neutral position. The background noise from the fans of the robots is present in all videos in the Noisy condition.

3.3 Procedure

Participants interacted twice with the robot, once with the robot's motor noises activated (condition: Noisy) and once deactivated (condition: Quiet). The sessions were

[2] https://github.com/robotology/speech/tree/master/svox-speech

done one to two weeks apart. The presentation order to the two conditions was pseudo-randomized across the children.

In both sessions, the participant was invited to sit in front of the laptop on which the game was launched. The experimenter sat on the left side of the participant and was controlling the flow of the game by means of an external keyboard connected to the laptop. The task evolved as follows: The robot presented itself and introduced the first game, the arm imitation game: "*Do with me the arm movements*". Then, the child underwent two training trials to ensure the task was understood. When ready, the 20 trials of the imitation task were played on the laptop. For these 20 trials, the set of five arm movements was repeated four times in random order. While doing the movements, the robot did not speak to the child. The experimenter inserted by means of the keyboard a value "correct/incorrect" for the child imitation movement. If the correct movement or any movement close to the one requested was done, the next movement was presented. If incorrect, the robot repeated the movement up to three times, and if the performed movement was still incorrect, the next movement was played. At the end of the 20 trials, the child was offered a short break. Then, the robot introduced the "Simon says" game as follows: "*Do with me the arm movements, but only when I say 'iCub does'. If I do not say 'iCub does', you should not move.*". The child was presented with two training trials to ensure the task was understood. If needed, the experimenter and the child's therapist explained the task again until understanding from the children was reached. When ready, the 20 trials of the "Simon says" game were played. For these 20 trials, the five arm movements were repeated four times in random order. In these 20 trials, 15 of them were valid prompts in which iCub said "iCub does" and five of them were invalid prompts in which iCub did not instruct "iCub does". Each of the five movements was invalid once. For each movement, the robot instructed which movement it was going to perform. The instruction was pronounced before the execution of the movement. Similarly to the previous game, the experimenter scored correctness of the movement by means of the keyboard. A trial was considered correct if the child performed a movement close to the one demonstrated by the robot when it said "iCub does" and if the child stayed still when the robot did not say "iCub does". A trial was considered incorrect if the child did an incorrect movement when the robot said "iCub does" and if the child moved with iCub when the robot did not say "iCub does". No trial was repeated. At the end of the 20 trials, the robot said goodbye to the child. The flow of the game can be seen in Figure 2.

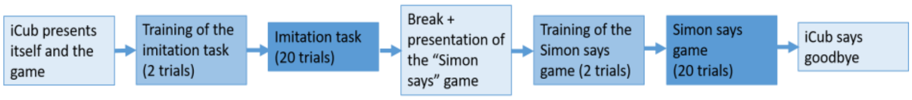

Fig. 2. Flowchart of the experimental procedure.

3.4 Measures

The participants' performance in both Imitation game and the "Simon says" game were scored. For the Imitation game, the children obtained one score of max. 20 points (one point for each correct trial). For the "Simon says" game, the children obtained two scores, one on 15 points-scale for the congruent condition (one point when they correctly imitated the robot when prompted to) and one of 5 points-scale for the incongruent condition (one point when they correctly did not imitate the robot when no prompt was made by the robot). We divided both scores by 15 and 5, respectively, to obtain performance scores.

Participants were screened for their sensory sensitivity by means of the Short Sensory Profile (SSP) [23], see Table 2. The SSP enables obtaining sensory processing patterns of children diagnosed with ASD with respect to demands related to everyday situations. The questionnaire investigates seven behaviors: Tactile Sensitivity, the Taste/Smell Sensitivity, the Movement Sensitivity, the Under-responsiveness/Seek Sensation, the Auditory Filtering, the Low Energy/Weak, and the Visual/Auditory Sensitivity. A general score summing the seven behaviors is also provided. The lower the score in a category, the more the child differs from typical behavior. The SSP provides a categorization in three groups based on the scores: "Typical behavior" (group 1), "Probable difference to typical behavior" (group 2), and "Certain difference to typical behavior" (group 3). We investigated the children's performance in the games regarding their Auditory Filtering and Visual/Auditory Sensitivity categorizations. Indeed, Auditory Filtering evaluates one's distraction by ambient noise or difficulty hearing what is said. Visual/Auditory Sensitivity assesses negative responses to unexpected noises or lights or blocking behaviors as putting the hands on the ears to block sounds or on the eyes to block lights.

Participants' IQ was screened using the Italian versions of Griffiths' Developmental Scales [24], and their autism level with the ADOS screening tool [21] which enable categorization of the children's impairment in three levels (from 1, the less impaired, to 3, the more impaired), see Table 1.

Table 2. Participants' mean scores and group population for the Short Sensory Profile. Each displayed behavior can be categorized in three groups: "Typical behavior" (group 1), "Probable difference to typical behavior" (group 2), and "Certain difference to typical behavior" (group 3)

SSP	**Auditory Filtering**	**Visual/Auditory Sensitivity**
141.6 ± 20.9	19.4 ± 5.3	20.2 ± 8.8
1: N=3; **2**: N=5; **3**: N=6	**1**: N=3; **2**: N=3; **3**: N=8	**1**: N=9; **2**: N=4; **3**: N=1

4 Results

Imitation game

Regarding the imitation game, all children performed the 20 movements or did movements close to the one requested by the robot during the imitation game in both conditions.

"Simon says" game

We performed a 2x2x2 ANOVA with the within-subjects factors Condition (noisy vs. quiet), Congruency (congruent vs. incongruent) and the between subject factor of Visual/Auditory Sensitivity (group 1 vs. group 2+3) on the dependent variable of Simon

Says scores. Two similar 2x2x2 ANOVA were performed, one with the Auditory Filtering (group 1 vs. group 2 vs. group 3) as between subject factor, and the second with the ADOS levels (group 1 vs. group 2 vs. group 3). Finally, a 2x2x2 ANCOVA with the within-subjects factors Condition (noisy vs. quiet), Congruency (congruent vs. incongruent) and the IQ as covariate on the dependent variable of Simon Says scores.

For the Visual/Auditory Sensitivity categorization, we grouped together the participants from groups 2 and 3 as group 3 only had one participant. The Congruency factor showed a significant difference ($F(12,2)=24.3;\ p<0.001$) with the "Simon says" score in the congruent condition ($M=0.924;\ SD=0.115$) being higher than the one in the incongruent condition ($M=0.421;\ SD=0.312$). The interaction effect Condition (noisy vs. quiet) x Congruency (congruent vs., incongruent) x Visual/Auditory Sensitivity (level 1 vs. level 2/3) was also significant ($F(12,2)=4.748,\ p=0.050$). We performed Paired-Samples T-Test on the score for each interaction Condition x Congruency for each of the two groups of the Visual/Auditory Sensitivity categorization. Participants within typical sensory sensitivity (group 1) showed a significant difference between congruent and incongruent trials in both the Quiet and Noisy conditions (Quiet: $t=4.124,\ p=0.003$; Noisy: $t=3.186,\ p=0.013$). Participants with a probable difference in sensory sensitivity in vision and audition (group 2 + group 3 together) showed a significant difference between congruent and incongruent trials in the Noisy condition ($t=3.373,\ p=0.028$). These results are shown in Figure 3. Independent T-Test to compare the groups on the score for each interaction Condition x Congruency were all non-significant.

For the Auditory Filtering categorization of the SSP, the ADOS level, and the IQ, no significant effect was found except for the Congruency on the children's performance in the "Simon says" game.

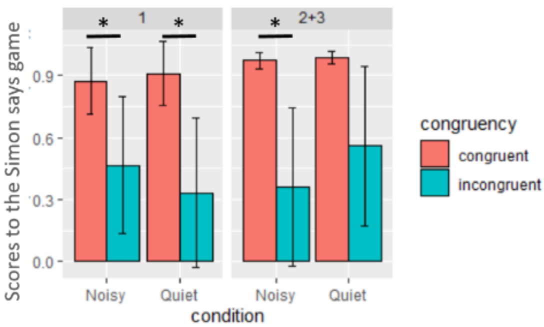

Fig. 3. "Simon says" scores for each groups of the Visual/Auditory Sensitivity categorization of the SSP.

Children's comments on motor noises

In addition to the scoring, the comments of the children during the interactions were reported by the experimenter immediately after the session. Three children made spontaneous comments about the motor noises from the robot. During the Noisy condition session, one child asked why the robot did these motor noises. He did not recall these motor noises from a previous interaction with the real robot iCub (all participants had previously interacted with the physical robot iCub for another experiment). During the second session, another child noticed that this time, the robot was silent (Quiet condition). He was very happy about it and declared that it helped him focus better. On the contrary, in the second session in Quiet condition, yet another child noticed the absence of the motor noises and said he disliked it and preferred when the robot made motor noises.

5 Discussion and Conclusion

In this study, we developed an imitation game and a "Simon says" game with iCub for children diagnosed with ASD. We aimed to evaluate if the motor sounds of the robot had an impact on the children's performance. From previous observations in imitation games with robots for children diagnosed with ASD literature, we expected that the children to show variation in their performance [11]–[15]. However, during the simple imitation game, the children all performed correctly the task. An explanation for this result would be that our participants have medium to low impairment according to the ADOS screening tool (only one participant was showing high level of impairment). We did not find any difference between the two auditory conditions of the experiment (Quiet vs. Noisy).

Regarding the "Simon says" game, the presence or absence of the robot's motor noises did not influence the participants' performance. We observed significant differences between the congruent and incongruent trials of the game, pointing out the children's impairments in response inhibition. As expected, we found that the SSP Visual/Auditory Sensitivity categorization plays a role in the children's performance in the "Simon says" game. We observed that participants who show typical behaviors in Visual/Auditory sensitivity showed to be distracted by the incongruent trials in both Quiet and Noisy conditions. Participants who show atypical behaviors only showed this distraction during the Noisy condition. The children showing typical behaviors to visual and auditory sensitivity got distracted in both conditions, suggesting that different auditory conditions did not beneficiate or penalized them. However, the children who were reported to react badly to loud, unexpected noises appeared to be more focused on the "Simon says" game in a quiet environment, suggesting they beneficiate from a quieter environment. In addition to these results, two children expressed to the experimenter that they noticed the change of condition (Quiet and Noisy robot) between the two sessions. They both expressed a different opinion, showing that the motor noises can be pleasant to some or, on the contrary, prevent focusing. These results highlight the impact of auditory sensory sensitivity of children with ASD during interactions with a robot. However, it should be noted that the children in this experiment were mainly high functioning (only one participant was in the lower category of the ADOS screening), and sensory sensitivity can be more dramatic in lower-functioning autism. Also, all children had already been exposed to iCub and its motor noises, and this might have increased their level of tolerance to the noise.

For reasons of experimental control, the experiment was done on a computer screen. Future works should investigate the sounds of the motors and the way they are perceived by the participants with a real robot. In addition, although robots on screens are shown to create a lower engagement from the users (see [25], [26]), the children spoke to the robot on the screen during the sessions (e.g. waved hello and goodbye, answered to the robot that they understood the rules of the games, general comments about the game, etc). This observation can support the idea to use screen-based interaction when real interaction with the robot is not possible.

Acknowledgments

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