Imitation, focus of attention and social behaviours of children with autism spectrum disorder in interaction with robots

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Many studies have shown that using robot platforms can be effective for teaching children with autism spectrum disorder (ASD). The aim of this study was to compare performance on an imitation task, as well as focus attention levels and the presence of social behaviours of children with ASD and typically developing (TD) children during an imitation task under two different conditions, with robots and human demonstrators. The results suggested that TD children did not imitate more than children with ASD. Children with ASD did not imitate the robot more than they imitated a person, but they showed more focused attention to robots and expressed more social behaviours in interaction with the robots. Behaviours that were significantly more present in ASD children than in TD children included touching the robot in the robot demonstrator condition and focusing on the robot in the person demonstrator condition. This implies a possible preference of children with ASD towards robots rather than towards people.

Keywords: imitation, autism spectrum disorder, humanoid robot

Autism spectrum disorder (ASD) is a developmental condition characterized by difficulties in social communication and interaction, accompanied by the presence of stereotyped behaviours, restricted interests, cognitive inflexibility and/or sensory sensitivities (American Psychiatric Association, 2014). Children with ASD face various developmental challenges that affect their everyday living. Some studies suggest that imitation skills represent one of the core problems in ASD (Rogers & Pennington, 1991; Williams et al., 2004) due to the interrelationship of imitation with the development of cognitive and social skills.

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Imitation as the backbone of acquiring new social skills in infants and young children

Imitation is the ability to reproduce observed behaviour, and it is a crucial learning tool in childhood. There are two roles of imitation in the child's development: learning new skills and engaging in socio – emotional exchanges with people in their environment (Uzgiris, 1981). Barr and Hayne (2003) found that 12- to 18-month-old children master one to two new behaviours per day through imitation. Numerous studies (e.g., Charman et al., 2000; Ingersoll & Schreibman, 2006; Poon et al., 2012; Toth et al., 2006) have indicated that imitation, along with joint attention and play, affects the language and communication development of typically developing (TD) children and children with ASD. Imitation skills seem to be connected to early forms of understanding of mental states of others. During imitation of facial expressions, children must combine their perception of the behaviour of others with their own senses and motor coordination in the specific moment. This affects the emotional connection between the child and the parent (McEwen et al., 2007).

In many aspects of imitation, children with ASD are different than their typical peers. They have more difficulty with spontaneous imitation than they do with induced imitation (Ingersoll, 2008). They present a lower frequency of imitation of actions with objects and gestures (Wild et al., 2012), although they perform better in imitation of actions with objects than in imitation of gestures (Ingersoll & Meyer, 2011). They also have more difficulty imitating senseless actions (Ingersoll & Meyer, 2011) and complex activities (Vivanti & Hamilton, 2014).

Therefore, imitation training is one of the key areas in interventions for children with ASD. Behavioural interventions have been shown to be effective in teaching imitation to children with ASD (Hwang & Hughes, 2000; Ingersoll & Gergans, 2007; Ingersoll et al., 2007).

Social assistive robotics in children with ASD

Advances in technology, offer greater possibilities of using robots in ASD interventions (Chung, 2021). Humanoid robots can provide social cues, such as those produced by humans in interaction and communication, like eye contact, head movements, gestures, and a human-like voice. Using robots can overcome various barriers that arise from face-to-face interaction for children with ASD (Huijnen et al., 2017). Children with ASD show a higher preference for robots compared to humans (Bird et al., 2007; Chaminade et al., 2012; Kim et al., 2013; Scassellati et al., 2012). Feil-Seifer and Mataric (2005, 2009) define social assistive robotics

as using social robots for the purpose of providing support to users by making their social interaction easier. In children with ASD, robots represent an interactive device with important social characteristics that enable teaching, motivation, and changes in behaviour (Scassellati et al., 2012). Robots are being used in clinical and research settings with increased frequency (Duquette et al., 2008) because their simple, inanimate, and predictable characteristics are useful for children with ASD. They also provide the unique opportunity for the quantification of social behaviours, since they are designed to detect, measure and respond to social behaviours (Tapus et al., 2007). Chevalier et al. (2020) emphasized the role of robots in studying joint attention and social conditions. Robots can provide a high degree of experimental control with relatively high ecological validity. They offer a repeatable, objective, and quantitative assessment of social response, which minimizes the personal biases of evaluators.

Robots were used in ASD intervention to target skills in different domains, such as communication, social/interpersonal interactions and relations, play, emotional wellbeing, sensory experiences and coping, motor experiences and skills, recognition of basic emotions, preschool skills, and functioning in daily life (Bartl-Pokorny et al., 2021; Huijnen et al., 2016; Jouaiti & Hénaff, 2019; Pennisi et al., 2016).

Robot use for imitation learning and elicitation of social behaviours in children with ASD

Existing studies (for example, Bird et al., 2007; Duquette et al., 2008; Peca et al., 2015; Pierno et al., 2008; Pioggia et al., 2008; Taheri et al., 2020; Tapus et al., 2012; Zheng et al., 2016) suggest that using social robots can be effective in teaching imitation skills to children with ASD. In most of the available studies, children with ASD show a preference towards robots. Furthermore, in some studies, children imitate robots more than humans (Bird et al., 2007; Pierno et al., 2008; Pioggia et al., 2008; Zheng et al., 2016), while in others, they imitate human demonstrators more (Costa et al., 2018; Duquette et al., 2008; Taheri et al., 2020).

Beyond imitation, robots can elicit various social behaviours of children with ASD (Aryania et al., 2021), specifically joint attention (Anzalone et al., 2014; Duquette et al., 2008), social engagement (Scassellati et al., 2012), verbalization (Kim et al., 2013), eye contact (Simut et al., 2016) and prosocial behaviours (Kim et al., 2021). Some studies have found that robots are better than humans in eliciting joint attention (Duquette et al., 2008), communication (Vanderborght et al., 2012), and imitation (Pierno et al., 2008). Other studies have found that robots are similar to humans in eliciting communication (Huskens et al., 2015)

and joint attention (Tapus et al., 2012). There are also studies that have shown that a robot was less successful than a person at eliciting imitation of body movements (Duquette et al., 2008) and joint attention (Anzalone et al., 2014).

It is important to note that the small sample size in many of these studies does not allow for the generalization of the results. Moreover, different robot platforms were used (FACE robot, NAO robot), which is problematic given children's preference for different morphological forms (Scassellati et al., 2012). Finally, children with ASD are a very heterogeneous population that should be considered in making conclusions about the whole population.

The results of previous studies on the role of the robot in intervention and diagnostic processes and differences between TD children and children with ASD in interaction with robots are still inconclusive. The results regarding whether robots can be, at least as effective as people, to teach abilities to children with ASD and to elicit social behaviours are also mixed.

The aim of this study is to compare performance on imitation tasks and the occurrence of accompanied social behaviours of children with ASD and TD children under two different conditions, with robots versus human (person) demonstrators. Instead of pure motoric imitation, an imitation task involving real objects in the environment was proposed, as well as a task that also includes joint attention skills.

Methods

Participants

The participants were 24 preschool children divided into two groups. The first group consisted of 12 children (4 girls, 8 boys) with ASD. They were on average 5.2 years old ($SD = 0.63$), with mental age between 2 and 3 years. Their ASD diagnosis was confirmed in clinical settings by a team of experts, including a psychologist, speech and language pathologist, special educator, and paediatrician, and was based on the interview with parents and assessment of the child. All children met DSM-5 (American Psychiatric Association, 2014) diagnostic criteria for ASD. The second group consisted of 12 (2 girls, 10 boys) TD children. Children in this group were between 2 and 3 years old (on average 2.6 years old ($SD = 0.2$) and without medical conditions that would interfere with participation in this study. The chronological ages of the two groups of participants were different, but their mental ages were the same. This means that we should expect the same level of cognitive infrastructure in both groups of children. Unfortunately, many studies did not consider the mental age of the children and only considered the chrono-

logical age. Furthermore, in some studies there were no cognitive measurements or even no mention of the participant's cognitive status (low-functioning or high-functioning ASD).

Procedure

After the initial interview, in which the study was explained and the consent of the parent was obtained, one parent entered the room with the participating child. Parents were instructed to behave neutrally during tasks. The room was 15 square metres large, with one couch on which the parent was asked to sit and a small desk where demonstrators (robot or human) performed the imitation task (see Figure 1).

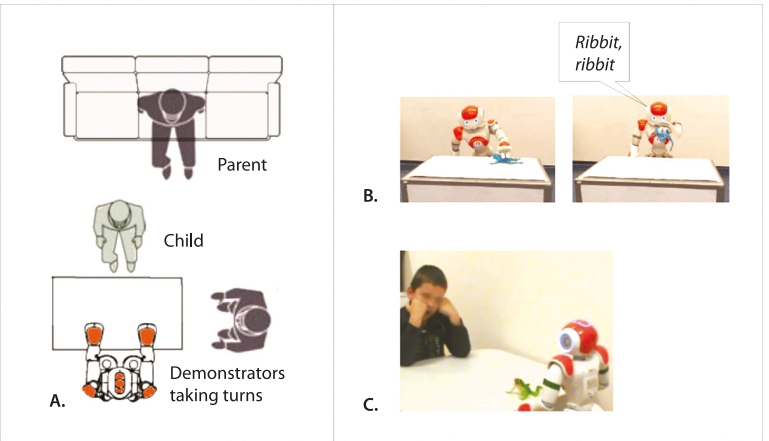

Figure 1. A. The layout of the room. The active demonstrator was always in front of the child, while the other demonstrator was at the side; B. Imitation task demonstrated by robot demonstrator; C. Child focused on the robot demonstrator before presenting the imitation task

Humanoid robot NAO H25 Atom was used as a robot demonstrator. Nao is a 58 cm tall humanoid robot with 25 degrees of freedom (DOF), and each hand has 5 DOFs. It has a humanoid look with simplified human characteristics that make it more attractive as an interactive partner for children (Shamsuddin et al., 2012). It is equipped with two high definition (720p) cameras, two speakers, four microphones and several other sensors, such as ultrasound range sensors, tactile sensors, force sensitive resistors, accelerometers, etc. It runs the OpenNAO operating system, based on the Gentoo Linux distribution, on an Intel Atom Z530 processor. More technical details are described in Petric et al. (2014) and Petric et al. (2017).

The imitation task was conducted on an individual basis in two conditions, one with the robot and one with a human demonstrator. The robot performed the targeted movement and gave verbal instructions in the robot trial, similar to humans in the human trial. The condition order was changed for each participant to reduce sequence effects. Both demonstrators were present in the room during the entire procedure. The task consisted of the presentation of an action with the toy frog followed by a verbal request for imitation ("Now you do it!"). The demonstrator showed the child the frog, made a frog-like arm movement, which represented the frog jumping, while reproducing the sound of a frog ("ribbit, ribbit"). This task is a standardized task used in the Autism Diagnostic Observation Schedule (ADOS-2; Lord et al., 2012). If the child performed a full imitation, the task was finished. The task was repeated up to three times in total, so the child had three opportunities to respond correctly. There were no practices before the task presentation. The robot was turned off during human trials, and the human was as neutral as possible during robot trials. The robot required some human assistance on two levels: (1) engineer controlling execution of the task in the room and/or outside the room where the experimental session was in progress (for example, pausing the execution if the child was not oriented towards robot); (2) examiner in the room helping the execution if necessary (for example, if the child takes the frog and throws it away, the human examiner would bring it back, which happened on few occasions). All conditions when assistance was disruptive were removed from the final analysis.

Audio and video recordings were started when the child and parent entered the room and stopped after the child's performance on the last trial. Video analysis included coding of three groups of behaviours: imitation, focus of attention and social behaviours. A detailed description of the measures is presented in Table 1. Video analysis was completed by two independent observers who were blinded to the ASD status of the child. Interobserver agreement was measured on 20% of videos. Agreement between observers estimated by Cohen's kappa values was 0.92.

Imitation behaviours were coded for every trial as no imitation, partial imitation or full imitation). The presence or absence of attention focus and social behaviours were coded in each second during all trials and computed as the proportion of time each social behaviour was present. Proportion was used as an adequate measure of incidence due to differences in the duration of the child's performance, as well as differences in the duration of demonstrations between the robot and the human.

Table 1. Description of coded behaviours

	Variable	Definition
Imitation	No imitation	Child does not react at all, or moves the frog in a way that is not similar to the targeted movement
	Partial imitation	Child performs movement similar to the targeted movement, but the movement is imprecise and/or partial
	Full imitation	Child performs full correct set of movements, with all the components, as the demonstrator (verbal component is not necessary).
Focus of attention	Focus on object of imitation	Child directs gaze/attention towards an object of imitation (frog)
	Focus on robot	Child directs gaze/attention towards robot (when robot is not demonstrator but is present in the room) *only measured in condition with human demonstrator
Social behaviours	Gaze direction	Child directs gaze towards the (robot or human) demonstrator.
	Touch	Child touches (robot or human) demonstrator.
	Approach	Child is getting closer and stays closer to the (robot or human) demonstrator.
	Social interaction	Child engages in interaction and/or communication with person(s) in the room verbally or nonverbally.
	Speech/ Vocalization	Child speaks or vocalizes during the task.

Results

The number of children who imitated both conditions (robot as demonstrator and person as demonstrator) are shown in Table 2. The difference in the number of children who imitated the robot demonstrator between the group of TD children and children with ASD was calculated with the chi square test. The difference in the number of children who imitated the person demonstrator between the group of TD children and children with ASD was also calculated with the chi square test. The results of Chi square test analysis found no differences between children with ASD and TD children in either condition (robot and human demonstrator) ($p > .05$).

Descriptive statistical data on the focus of attention and social behaviours for both groups (the person demonstrator and robot demonstrator) are shown in

Table 2. Number of children (out of 12 in each group) that imitated the frog jumping movement in two conditions – robot demonstrator and human demonstrator

Children with ASD ($N=12$)						
Robot demonstrator			Human demonstrator			
No imitation	Partial imitation	Full imitation		No imitation	Partial imitation	Full imitation	
Total	6	2	4	4	2	6
Typically, developing children ($N=12$)						
Robot demonstrator			Human demonstrator			
No imitation	Partial imitation	Full imitation		No imitation	Partial imitation	Full imitation	
Total	8	0	4	7	1	4

Table 3, with data on the differences in the focus of attention and social behaviours between the group of TD children and children with ASD by the Mann – Whitney U test in Table 4.

Table 3. Descriptive statistics for focus of attention and social behaviours for children with autism spectrum disorder (ASD, $N=12$) and typically, developing children (TD, $N=12$)

	Demonstrator		**Group**	**M**	**SD**	**MAX**	**MIN**
Focus of attention	**Focus on object of imitation**	Robot	ASD	.46	.00	.93	.38
			TD	.22	.00	.87	.34
		Person	ASD	.80	.14	1.00	.28
			TD	.78	,00	1.00	.29
	Focus on robot	Person	ASD	.09	.00	.43	.14
			TD	.00	.00	.00	.00
Social behaviour	**Gaze direction**	Robot	ASD	.52	.07	1.00	.39
			TD	.73	.13	1.00	.32
		Person	ASD	.10	.00	.60	.20
			TD	.27	.00	1.00	.30
	Touch	Robot	ASD	.11	.00	.53	.16
			TD	.00	.00	.00	.00
		Person	ASD	.02	.00	.20	.06
			TD	.00	.00	.00	.00
	Approach	Robot	ASD	.66	.00	1.00	.43
			TD	.37	.00	1.00	.45

Table 3. *(continued)*

	Demonstrator		Group	M	SD	MAX	MIN
		Person	ASD	.70	.00	1.00	.33
			TD	.42	.00	1.00	.51
	Social interaction	Robot	ASD	.00	.00	.00	.00
			TD	.04	.00	.13	.06
		Person	ASD	.00	.00	.00	.00
			TD	.02	.00	.20	.06
	Speech/vocalization	Robot	ASD	.09	.00	.40	.13
			TD	.12	.00	.33	.12
		Person	ASD	.18	.00	.60	.20
			TD	.00	.00	.00	.00

* Numbers represent the proportion of time every social behaviour was present during the demonstration of action.

Table 4. Differences in the focus of attention and social behaviours between children with ASD and TD children during the demonstration of action in the imitation task (Mann – whitney u test)

		Demonstrator	Z	P
Focus of attention	**Focus on object of imitation**	Robot	−1.638	.101
		Person	−0.395	.693
	Focus on robot	/	/	/
		Person	−2.134	**.033***
Social behaviour	**Gaze direction**	Robot	−1.149	.251
		Person	−1.889	.059
	Touch	Robot	−2.440	**.015***
		Person	−1.000	.317
	Approach	Robot	−1.464	.143
		Person	−1.119	.263
	Social interaction	Robot	−2.444	**.015***
		Person	−1.000	.317
	Speech/vocalization	Robot	−0.724	.469
		Person	−3.019	**.003***

* 5% significance level

The results show that children with ASD paid more attention to the robot than TD children when the imitation task was performed by a human demonstrator ($Z = -2.134$, $p = .033$). There was no difference between groups in the focus on the object of imitation when either the robot or the human performed the frog movement.

In the ASD group, *Touch* was more frequent in the robot demonstrator condition ($Z = -2.440$, $p = .015$) and *Speech/Vocalization* in the person demonstrator condition ($Z = -3.019$, $p = .003$). In the TD group, *social interaction* was more frequent in the robot demonstrator condition ($Z = -2.444$, $p = .015$).

Differences in the focus of attention and social behaviours of children with ASD between the person demonstrator and robot demonstrator were assessed by the Wilcoxon signed-rank test and are presented in Table 5. The results show that *gaze direction* was more frequent in the robot demonstrator condition ($Z = -2.475$, $p = .013$) and *focus on the object of imitation* in the person demonstrator condition ($Z = -1.963$, $p = .050$).

Table 5. Wilcoxon signed-rank test for paired focus of attention and social behaviours during the demonstration of task in a group of children with ASD

	Focus on object of imitation (robot vs. human)	Gaze direction (robot vs. human)	Touch (robot vs. human)	Approach (robot vs. human)	Social interaction (robot vs. human)	Speech/ vocalization (robot vs. human)
Z	−1.963	−2.475	−1.841	−0.280	0.000	−1.355
p	**.050***	**.013***	.066	.779	1.000	.176

* = 5% significance level

Discussion

Analysis of the results of children's performance on imitation tasks has shown that the quantity of imitation is similar between children with ASD and TD children in both conditions (robot as demonstrator and person as demonstrator). Data has shown that many children never succeeded in imitating either. Children, sporadically, in both groups, either showed no reaction or made some playful movements with the frog that were not similar to the target behaviour. It is assumed that various factors could have influenced this behaviour, including interest in frog, interest in the demonstrator, attention, and/or shyness. The results are therefore not in line with past studies that found that children with ASD imitated a robot more than a person (Pierno et al., 2008) or with research that found that children with

ASD imitated a person more than a robot (Duquette et al., 2008). Other studies, however, are consistent with our findings that children did not imitate a robot more than a person (Duquette et al., 2008; Taheri et al., 2020; Tapus et al., 2012).

It is possible that improving imitation skills are a priority for children with ASD, and a similar intervention, combined with verbal requests, is used in teaching imitation. In this way, children in the ASD group may have been in a familiar situation, which may make up for the greater ability of the TD group to imitate behaviour. Some TD children were cautious and observed tasks from a safe distance, some observed first and made some actions on the second or third attempt, and a few approached the robot demonstrator or person demonstrator immediately. Additionally, although children in both groups were equalized by mental age, they did not have the same level of imitation skills. The task may have been too easy for some TD children, and they perhaps did not find it attractive enough to perform it. Furthermore, performance on imitation tasks can also depend on interindividual differences between different children with ASD. Chevalier et al. (2017) found that performance might be connected with sensory preferences. In their study, children with more reliance on visual cues and hyporeactivity to proprioceptive cues performed better on imitation tasks. One other explanation is that children with low-functioning autism have more difficulty understanding the communication intent from the limited motion capabilities of the robot.

Compared to TD children, children with ASD showed some behaviours that might indicate increased focus and interest of robots. Additionally, based on their behaviour, ASD children showed more interest in the robot demonstrator than the person (Figure 2).

Compared to TD children, children with ASD touched the robots more often and interacted less with the people present in the room when robots were demonstrators. When a person was demonstrator, ASD children looked at the robot more often than TD children. These behaviours strongly suggest interest in robots and imply a possible preference of children with ASD towards robots rather than towards people. Previous research has also shown that children with ASD prefer to play with a robot more than with humans, have more positive attitudes towards robots (Costa et al., 2018) and are more engaged with robots than humans (Zheng et al., 2016). This can also indicate that children were more comfortable interacting with the robot than with the person. These results are in agreement with the studies that compared children's attention towards a robot and towards a person and found that children with ASD directed more attention towards the robot (Aryania et al., 2020; Huijnen et al., 2017; Peca et al., 2015; Warren et al., 2015; Zubak et al., 2018).

Social interaction was significantly more present in TD children than in ASD children under the robot demonstrator condition. This finding can be explained

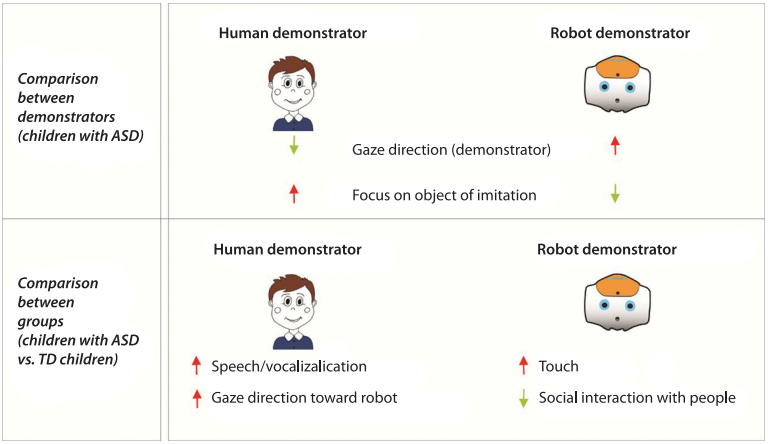

Figure 2. Differences in focus of attention and social behaviours noticed in two settings – in children with ASD when imitation task was performed by human and robot demonstrator and between children with ASD and TD children
Red arrows pointing upwards indicate a significant increase, while green arrows pointing downwards indicate a significant decrease in the frequency of each behaviour in the comparison shown.

by the social motivation of TD children to share experiences and comment on new and unusual situations, as opposed to children with ASD, who often lack social motivation in interactions (Maljaars et al., 2011). However, since differences between groups were noticed only when the robot was a demonstrator and not when the human demonstrator performed the task, it can be concluded that observed differences cannot be explained solely based on the communication skills of the ASD child, but might indicate higher focus of attention on robots in ASD children that does not "allow" them to simultaneously interact both with robots and humans. The only behaviour present at a higher rate in children with ASD than in TD children when the person was a demonstrator was the appearance of vocalization or speech, which was unexpected. Qualitative analysis of the study revealed that verbal imitation was not noticed in any ASD child and that most of the vocalization and speech was undirected, that is, did not serve social function. Therefore, it may be concluded that observed vocal behaviours might be self-stimulatory behaviours.

When the behaviours of children with ASD were compared in the robot demonstrator and human demonstrator conditions, a higher incidence of gaze towards the demonstrator was noticed when the robot was the demonstrator, and a higher focus on the object of imitation (frog) was observed in the human demonstrator condition. It is possible that the increased interest in robot-directed

behaviours of ASD children suggests that they more often look at robots and do not pay attention towards other objects. It is generally known that children with ASD aged 2–4 years are much less likely to initiate joint episodes, i.e., they have a lower ability to share and coordinate attention with another person and an object (Rice et al., 2016). In this case, that could mean that attention directed towards robot occupies their attention system and coordination of attention between robot and object of imitation is reduced. Shared attention challenges could be reduced in the human demonstrator condition due to less interest in humans.

Although there is very different information on imitation in ASD, it is studied because this developmental skill is very complex, especially in the population of children with ASD who have unique cognitive infrastructure and are largely heterogeneous. However, the focus of this paper is, not only on imitation, but also on the different patterns of behaviour children with ASD display when compared with TD children in two different learning settings, including the robot or human as demonstrator of the task. Additional information on their focus of attention and other social behaviours add to the quality of observed differences. Additionally, there is a clear experimental procedure, compared to clinical studies, and the existence of a control group, unlike many other studies (Chevalier et al., 2020; Jouaiti & Hénaff, 2019), which brings additional value. Furthermore, although previous studies included body movement imitation (for example Chevalier et al., 2017; Duquette et al., 2008; Ranatunga et al., 2013; Taheri et al., 2020), in this study, object imitation was the focus, which is occurs in fewer studies (for example Pierno et al., 2008). Therefore, the data serves as a starting point for a new, clearer, and detailed analysis of observed phenomena.

The limitations of this study are similar to those of comparable studies, and include the small, nonrepresentative, convenience sample of participants from a university clinic or therapeutic centre in a large city. Although procedures were explained to the parent before the session started, some parents tried to direct their child during the procedure. It must also be noted, that children found many interesting toys in the waiting room, and some did not want to leave, which may have affected their attention and motivation levels. Other limitations are technical, and included the robot performance that was not completely independent and needed the assistance of a person demonstrator, some dropping of objects and the robot falling, that could affect the behaviour of the children.

This study, unlike others (Pierno et al., 2008; Pioggia et al., 2008; Zheng et al., 2016), has shown that children with ASD do not imitate robots more than a person demonstrator, but confirms previous findings that children with ASD show interest and are motivated by robots (Duquette et al., 2008; Kim et al., 2013; Peca et al., 2015; Scassellati et al., 2012). In summary, the results show that robot use can be efficient in children with ASD. The fact that children direct more attention

towards the robot and imitate the robot as much as a person represents increased learning opportunities for children with ASD. Therefore, it can be concluded that further research on the possibilities of using robots in ASD diagnosis and intervention can be valuable.

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References

American Psychiatric Association. (2014). *Diagnostic and statistical manual of mental disorders, 5th edition – DSM-5*. American Psychiatric Publishing.

Anzalone, S.M., Tilmont, E., Boucenna, S., Xavier, J., Jouen, A.-L., Bodeau, N., Maharatna, K., Chetouani, M., & Cohen, D. (2014). How children with autism spectrum disorder behave and explore the 4-dimensional (spatial 3D+time) environment during a joint attention induction task with a robot. *Research in Autism Spectrum Disorders*, *8*(7), 814–826. https://doi.org/10.1016/j.rasd.2014.03.002

Aryania, A., Aghdasi, H.S., Beccaluva, E.A., & Bonarini, A. (2020). Social engagement of children with autism spectrum disorder (ASD) in imitating a humanoid robot: A case study. *SN Applied Sciences*, *2*(6). https://doi.org/10.1007/s42452-020-2802-4

Aryania, A., Aghdasi, H.S., Heshmati, R., & Bonarini, A. (2021). Robust risk-averse multi-armed bandits with application in social engagement behavior of children with autism spectrum disorder while imitating a humanoid robot. *Information Sciences*, *573*, 194–221. https://doi.org/10.1016/j.ins.2021.05.067

Barr, R., & Hayne, H. (2003). It's not what you know, it's who you know: Older siblings facilitate imitation during infancy. *International Journal of Early Years Education*, *11*(1), 7–21.

Bartl-Pokorny, K.D., Pykala, M., Uluer, P., Barkana, D.E., Baird, A., Kose, H., Zorcec, T., Robins, B., Schuller, B.W., & Landowska, A. (2021). Robot-based intervention for children with autism spectrum disorder: A systematic literature review. *IEEE Access*, *9*, 165433–165450. https://doi.org/10.1109/ACCESS.2021.3132785

Bird, G., Leighton, J., Press, C., & Heyes, C. (2007). Intact automatic imitation of human and robot actions in autism spectrum disorders. *Proceedings Biological Sciences*, *274*(1628), 3027–3031. https://doi.org/10.1098/rspb.2007.1019

Chaminade, T., Fonseca, D.D., Rosset, D., Lutcher, E., Cheng, G., & Deruelle, C. (2012). FMRI study of young adults with autism interacting with a humanoid robot. In *2012 IEEE RO-MAN: The 21st IEEE international symposium on robot and human interactive communication* (pp. 380–385). IEEE. https://doi.org/10.1109/ROMAN.2012.6343782

Charman, T., Baron-Cohen, S., Swettenham, J., Baird, G., Cox, A., & Drew, A. (2000). Testing joint attention, imitation, and play as infancy precursors to language and theory of mind. *Cognitive Development*, *15*(4), 481–498. https://doi.org/10.1016/S0885-2014(01)00037-5

Chevalier, P., Kompatsiari, K., Ciardo, F., & Wykowska, A. (2020). Examining joint attention with the use of humanoid robots-A new approach to study fundamental mechanisms of social cognition. *Psychonomic Bulletin & Review*, *27*(2), 217–236. https://doi.org/10.3758/s13423-019-01689-4

Chevalier, P., Raiola, G., Martin, J., Isableu, B., Bazile, C., & Tapus, A. (2017). Do sensory preferences of children with autism impact an lmitation task with a robot? In *2017 12th ACM/IEEE international conference on human-robot interaction* (pp. 177–186). IEEE.

Chung, E.Y.-H. (2021). Robot-mediated social skill intervention programme for children with autism spectrum disorder: An ABA time-series study. *International Journal of Social Robotics*, *13*(5), 1095–1107. https://doi.org/10.1007/s12369-020-00699-w

Costa, A.P., Charpiot, L., Lera, F.R., Ziafati, P., Nazarikhorram, A., van der Torre, L., & Steffgen, G. (2018). A comparison between a person and a robot in the attention, imitation, and repetitive and stereotypical behaviors of children with autism spectrum disorder. In *Proceedings workshop on social human-robot interaction of human-care service robots at HRI2018* (pp. 1–4).

Duquette, A., Michaud, F., & Mercier, H. (2008). Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. *Autonomous Robots*, *24*(2), 147–157. https://doi.org/10.1007/s10514-007-9056-5

Feil-Seifer, D., & Mataric, M.J. (2005). Defining socially assistive robotics. In *9th international conference on rehabilitation robotics, 2005 ICORR 2005* (pp. 465–468). IEEE. https://doi.org/10.1109/ICORR.2005.1501143

Feil-Seifer, D., & Mataric, M.J. (2009). Toward socially assistive robotics for augmenting interventions for children with autism spectrum disorders. In O. Khatib, V. Kumar, & G.J. Pappas (Eds.), *Experimental robotics* (pp. 201–210). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-00196-3_24

Huijnen, C.A.G.J., Lexis, M.A.S., Jansens, R., & de Witte, L.P. (2016). Mapping robots to therapy and educational objectives for children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *46*(6), 2100–2114. https://doi.org/10.1007/s10803-016-2740-6

Huijnen, C.A.G.J., Lexis, M.A.S., Jansens, R., & de Witte, L.P. (2017). How to implement robots in interventions for children with autism? A co-creation study involving people with autism, parents and professionals. *Journal of Autism and Developmental Disorders*, *47*(10), 3079–3096. https://doi.org/10.1007/s10803-017-3235-9

Huskens, B., Palmen, A., Van der Werff, M., Lourens, T., & Barakova, E. (2015). Improving collaborative play between children with autism spectrum disorders and their siblings: The effectiveness of a robot-mediated intervention based on lego® therapy. *Journal of Autism and Developmental Disorders*, *45*(11), 3746–3755. https://doi.org/10.1007/s10803-014-2326-0

Hwang, B., & Hughes, C. (2000). Increasing early social-communicative skills of preverbal preschool children with autism through social interactive training. *Journal of the Association for Persons with Severe Handicaps*, *25*(1), 18–28. https://doi.org/10.2511/rpsd.25.1.18

Ingersoll, B. (2008). The social role of imitation in autism: Implications for the treatment of imitation deficits. *Infants & Young Children*, *21*(2), 107–119. https://doi.org/10.1097/01.IYC.0000314482.24087.14

Ingersoll, B., & Gergans, S. (2007). The effect of a parent-implemented imitation intervention on spontaneous imitation skills in young children with autism. *Research in Developmental Disabilities*, *28*(2), 163–175. https://doi.org/10.1016/j.ridd.2006.02.004

Ingersoll, B., Lewis, E., & Kroman, E. (2007). Teaching the imitation and spontaneous use of descriptive gestures in young children with autism using a naturalistic behavioral intervention. *Journal of Autism and Developmental Disorders*, *37*(8), 1446–1456. https://doi.org/10.1007/s10803-006-0221-z

Ingersoll, B., & Meyer, K. (2011). Do object and gesture imitation skills represent independent dimensions in autism? *Journal of Developmental and Physical Disabilities*, *23*(5), 421–431. https://doi.org/10.1007/s10882-011-9237-1

Ingersoll, B., & Schreibman, L. (2006). Teaching reciprocal imitation skills to young children with autism using a naturalistic behavioral approach: Effects on language, pretend play, and joint attention. *Journal of Autism and Developmental Disorders*, *36*(4), 487–505. https://doi.org/10.1007/s10803-006-0089-y

Jouaiti, M., & Hénaff, P. (2019). Robot-based motor rehabilitation in autism: A systematic review. *International Journal of Social Robotics*, *11*(5), 753–764. https://doi.org/10.1007/s12369-019-00598-9

Kim, E. S., Berkovits, L. D., Bernier, E. P., Leyzberg, D., Shic, F., Paul, R., & Scassellati, B. (2013). Social robots as embedded reinforcers of social behavior in children with autism. *Journal of Autism and Developmental Disorders*, *43*(5), 1038–1049. https://doi.org/10.1007/s10803-012-1645-2

Kim, S., Hirokawa, M., Matsuda, S., Funahashi, A., & Suzuki, K. (2021). Smiles as a signal of prosocial behaviors toward the robot in the therapeutic setting for children with autism spectrum disorder. *Frontiers in Robotics and AI*, *8*, 599755. https://doi.org/10.3389/frobt.2021.599755

Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., Bishop, S. L. (2012). *Autism Diagnostic Observation Schedule Modules 1–4, Second Edition [Manual]*. Western Psychological Services.

Maljaars, J., Noens, I., Jansen, R., Scholte, E., & van Berckelaer-Onnes, I. (2011). Intentional communication in nonverbal and verbal low-functioning children with autism. *Journal of Communication Disorders*, *44*(6), 601–614. https://doi.org/10.1016/j.jcomdis.2011.07.004

McEwen, F., Happé, F., Bolton, P., Rijsdijk, F., Ronald, A., Dworzynski, K., & Plomin, R. (2007). Origins of individual differences in imitation: Links with language, pretend play, and socially insightful behavior in two-year-old twins. *Child Development*, *78*(2), 474–492. https://doi.org/10.1111/j.1467-8624.2007.01010.x

Peca, A., Simut, R., Pintea, S., & Vanderborght, B. (2015). Are children with ASD more prone to test the intentions of the robonova robot compared to a human? *International Journal of Social Robotics*, *7*(5), 629–639. https://doi.org/10.1007/s12369-015-0317-8

Pennisi, P., Tonacci, A., Tartarisco, G., Billeci, L., Ruta, L., Gangemi, S., & Pioggia, G. (2016). Autism and social robotics: A systematic review. *Autism Research*, *9*(2), 165–183. https://doi.org/10.1002/aur.1527

Petric, F., Hrvatinić, K., Babić, A., Malovan, L., Miklić, D., Kovačić, Z., Cepanec, M., Stošić, J., & Šimleša, S. (2014). Four tasks of a robot-assisted autism spectrum disorder diagnostic protocol: First clinical tests. In *IEEE global humanitarian technology conference (GHTC 2014)* (pp. 510–517). IEEE. https://doi.org/10.1109/GHTC.2014.6970331

Petric, F., Miklić, D., Cepanec, M., Cvitanović, P., & Kovačić, Z. (2017). Functional imitation task in the context of robot-assisted autism spectrum disorder diagnostics: Preliminary investigations. In *2017 26th IEEE international symposium on robot and human interactive communication (RO-MAN)* (pp. 1471–1478). IEEE. https://doi.org/10.1109/ROMAN.2017.8172498

Pierno, A. C., Mari, M., Lusher, D., & Castiello, U. (2008). Robotic movement elicits visuomotor priming in children with autism. *Neuropsychologia*, *46*(2), 448–454. https://doi.org/10.1016/j.neuropsychologia.2007.08.020

Pioggia, G., Igliozzi, R., Sica, M. L., Ferro, M., Muratori, F., Ahluwalia, A., & De Rossi, D. (2008). Exploring emotional and imitational android-based interactions in autistic spectrum disorders. *Journal of CyberTherapy & Rehabilitation*, *1*(1), 49–61.

Poon, K. K., Watson, L. R., Baranek, G. T., & Poe, M. D. (2012). To what extent do joint attention, imitation, and object play behaviors in infancy predict later communication and intellectual functioning in ASD? *Journal of Autism and Developmental Disorders*, *42*(6), 1064–1074. https://doi.org/10.1007/s10803-011-1349-z

Ranatunga, I., Beltran, M., Torres, N. A., Bugnariu, N., Patterson, R. M., Garver, C., & Popa, D. O. (2013). Human-robot upper body gesture imitation analysis for autism spectrum disorders. In G. Herrmann, M. J. Pearson, A. Lenz, P. Bremner, A. Spiers, & U. Leonards (Eds.), *Social robotics ICSR 2013. Lecture notes in computer science* (pp. 218–228). Springer International Publishing. https://doi.org/10.1007/978-3-319-02675-6_22

Rice, C. E., Adamson, L. B., Winner, E., & McGee, G. G. (2016). A cross-sectional study of shared attention by children with autism and typically developing children in an inclusive preschool setting. *Topics in Language Disorders*, *36*(3), 245–265. https://doi.org/10.1097/TLD.0000000000000099

Rogers, S. J., & Pennington, B. F. (1991). A theoretical approach to the deficits in infantile autism. *Development and Psychopathology*, *3*(2), 137–162. https://doi.org/10.1017/S0954579400000043

Scassellati, B., Henny, A., & Matarić, M. (2012). Robots for use in autism research. *Annual Review of Biomedical Engineering*, *14*(1), 275–294. https://doi.org/10.1146/annurev-bioeng-071811-150036

Shamsuddin, S., Yussof, H., Ismail, L. I., Mohamed, S., Hanapiah, F. A., & Zahari, N. I. (2012). Humanoid robot NAO interacting with autistic children of moderately impaired intelligence to augment communication skills. *Procedia Engineering*, *41*, 1533–1538. https://doi.org/10.1016/j.proeng.2012.07.346

Simut, R. E., Vanderfaeillie, J., Peca, A., Van de Perre, G., & Vanderborght, B. (2016). Children with autism spectrum disorders make a fruit salad with Probo, the social robot: an interaction study. *Journal of autism and developmental disorders*, *46*(1), 113–126. https://doi.org/10.1007/s10803-015-2556-9

Taheri, A., Meghdari, A., & Mahoor, M. H. (2020). A close look at the imitation performance of children with autism and typically developing children using a robotic system. *International Journal of Social Robotics*, *13*(5), 1125–1147. https://doi.org/10.1007/s12369-020-00704-2

Tapus, A., Mataric, M., & Scassellati, B. (2007). Socially assistive robotics [grand challenges of robotics]. *IEEE Robotics & Automation Magazine*, *14*(1), 35–42. https://doi.org/10.1109/MRA.2007.339605

Tapus, A., Peca, A., Aly, A., A. Pop, C., Jisa, L., Pintea, S., Rusu, A. S., & David, D. O. (2012). Children with autism social engagement in interaction with Nao, an imitative robot: A series of single case experiments. *Interaction Studies*, *13*(3), 315–347. https://doi.org/10.1075/is.13.3.01tap

Toth, K., Munson, J., Meltzoff, A. N., & Dawson, G. (2006). Early predictors of communication development in young children with autism spectrum disorder: Joint attention, imitation, and toy play. *Journal of Autism and Developmental Disorders*, *36*(8), 993–1005. https://doi.org/10.1007/s10803-006-0137-7

Uzgiris, I. C. (1981). Two functions of imitation during infancy. *International Journal of Behavioral Development*, *4*(1), 1–12. https://doi.org/10.1177/016502548100400101

Vanderborght, B., Simut, R., Saldien, J., A. Pop, C., Rusu, A. S., Pintea, S., Lefeber, D., & David, D. O. (2012). Using the social robot probo as a social story telling agent for children with ASD. *Interaction Studies*, *13*(3), 348–372. https://doi.org/10.1075/is.13.3.02van

Vivanti, G., & Hamilton, A. (2014). Imitation in autism spectrum disorder. In F. R. Volkmar, S. J. Rogers, R. Paul, & K. A. Pelphrey (Eds.), *Handbook of autism and pervasive developmental disorders: Diagnosis, development, and brain mechanisms* (pp. 278–301). John Wiley & Sons, Inc.

Warren, Z., Zheng, Z., Das, S., Young, E. M., Swanson, A., Weitlauf, A., & Sarkar, N. (2015). Brief report: Development of a robotic intervention platform for young children with ASD. *Journal of Autism and Developmental Disorders*, *45*(12), 3870–3876. https://doi.org/10.1007/s10803-014-2334-0

Wild, K. S., Poliakoff, E., Jerrison, A., & Gowen, E. (2012). Goal-directed and goal-less imitation in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *42*(8), 1739–1749. https://doi.org/10.1007/s10803-011-1417-4

Williams, J. H. G., Whiten, A., & Singh, T. (2004). A systematic review of action imitation in autistic spectrum disorder. *Journal of Autism and Developmental Disorders*, *34*(3), 285–299. https://doi.org/10.1023/B:JADD.0000029551.56735.3a

Zheng, Z., Young, E. M., Swanson, A. R., Weitlauf, A. S., Warren, Z. E., & Sarkar, N. (2016). Robot-mediated imitation skill training for children with autism. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *24*(6), 682–691. https://doi.org/10.1109/TNSRE.2015.2475724

Zubak, I., Kovačić, Z., Petric, F., Stošić, J., Cepanec, M., & Šimleša, S. (2018). Reaction to robots in social and non-social contexts – comparison of children with autism spectrum disorders and their typical peers. *Hrvatska Revija za Rehabilitacijska Istraživanja*, *54*(2), 28–38. https://doi.org/10.31299/hrri.54.2.3

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