Speech characteristics of children with ASD to a humanoid robot and peers

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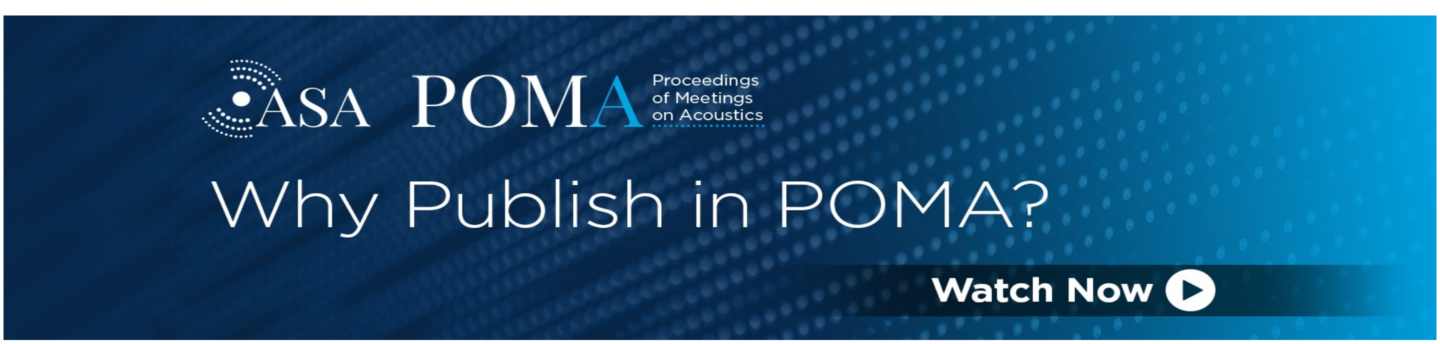

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Speech characteristics of children with ASD to a humanoid robot and peers

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Children with Autism Spectrum Disorder (ASD) display difficulty engaging in social interactions. How does the use of a NAO robot during a social skills intervention affect the speech of children with ASD? This study examined whether the use of a NAO robot during a social skills intervention affects the quantity and quality of speech in six children (mean age = 11.6 yrs., range = 10.5-12.6) with ASD who attended four weekly social skills intervention sessions. The speech quantity was defined as an overall speech rate (utterances per minute), initiation rate (utterances per minute addressing the robot/other child), and response rate (utterances per minute responding to the robot/other child). Mean length of utterance (MLU) in overall speech, initiations, and responses was also measured. A marginally higher initiation rate and overall MLU in speech to the robot were identified in later sessions. Children produced a significantly higher MLU in responses to the robot in later sessions. MLU for initiations were marginally higher than MLU for responses to the robot. No changes in speech rate or MLU in speech directed to other children were identified. This suggests children may require repeated exposure to the NAO robot before changes in speech characteristics are revealed.

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1. INTRODUCTION

Autism Spectrum Disorder (ASD) is characterized by difficulties in social communication and interaction and restricted and repetitive behaviors (American Psychiatric Association, 2013). For example, children with ASD typically display difficulty in reciprocal (e.g., initiating and terminating) conversations and engaging in social interactions (Paul, 2008). Recently, robot-mediated interventions have been widely explored in the treatment of social skill deficits among children diagnosed with ASD (Ismail et al., 2018, Scassellati et al., 2012; Soares et al., 2021). Humanoid robots, such as NAO (Softbank Robotics, 2021) are of interest because children with ASD may find them easier with which to interact (Shamsuddin et al., 2012). These robots may present fewer social cues that may be easier to interpret (Johnson & Myers, 2007; Shamsuddin et al., 2012). Previous research on robot-mediated interventions has focused predominantly on the quantity of speech to other humans (i.e., the adult instructor) or to the robot (Chung, 2019; Taheri et al., 2018), the pragmatic/social component of speech, and/or the characteristics of the non-verbal interactions with the robot (Albo-Canals et al., 2018). Very little information is known about whether the introduction of robots into the intervention changes the quality of child speech directed to the robot or other humans in the room (Albo-Canals et al., 2018; Taheri et al., 2018). Therefore, the aim of the current study was to examine both the quantity and quality of speech produced by children with ASD during a robot-mediated social skills intervention across time.

A. ROBOT-MEDIATED INTERVENTIONS WITH CHILDREN WITH ASD

Several different types of robots have been used in interventions for children with ASD including NAO, Keepon, Kaspar, and more (Huijnen et al., 2020; Huskens et al., 2015; Kozima et al., 2007; see Ismail et al., 2018 for review). One particular type of robot, NAO (see Figure 1), widely has been used in interventions for children with ASD (Ismail et al., 2018). Often, these robots serve as an assistant to a human instructor during the intervention (Chung, 2019) or as a peer/companion to the child with ASD (Saadatzi et al., 2018; Taheri et al., 2018). During a typical intervention session, the human serves as the primary change agent while the robot conducts various activities with the child serving as an assistant (Chung, 2019). The robot also can take the role of a peer/companion to the child and participates in games, elicits the child's attention, and practices conversation with the child (Huskens et al., 2015; Saadatzi et al., 2018; Taheri et al., 2018). Therefore, a robot can take either an assistant or peer/companion role during robot-mediated interventions for ASD.

The types of tasks robots perform during robot-mediated intervention are designed to facilitate social communication and conversational skills in children with ASD (Chung, 2019; Huijnen et al., 2020; Huskens et al., 2015; Kozima et al., 2007; Miyamoto et al., 2005; Robins et al., 2005; Taheri et al., 2018). These tasks include playing with Legos ® (Huskens et al., 2015), verbal, motor, and facial imitation tasks (Taheri et al., 2018), or role plays (Yun et al., 2017). Researchers have targeted a range of social skills including conversation initiations (Huskens et al., 2015; Miyamoto et al., 2005), responses (Chung, 2019; Huskens et al., 2015), eye contact (Chung et al., 2019), imitation (Robins et al., 2004; Taheri et al., 2018), and joint attention (Taheri et al., 2018). Robot-child interactions have primarily been comprised of two types of interactions: structured or naturalistic (Chung, 2019; Robins et al., 2005; Miyamoto et al., 2005; Huijnen et al., 2020; Huskens et al., 2015). In structured interactions, the adult instructor guides the child's interaction with the robot (Chung, 2019; Robins et al., 2005; Miyamoto et al., 2005). In naturalistic interactions, the child freely interacts with the robot (Huijnen et al., 2020; Huskens et al., 2015). Previous research has reported positive outcomes from robot-mediated social skill interventions for children with ASD (Chung et al., 2019; Kozima et al., 2007; Robins et al., 2005; Taheri et al., 2018).

B. QUANTITY AND QUALITY OF CHILD SPEECH DURING ROBOT-CHILD SOCIAL SKILLS INTERVENTIONS

Studies looked at the quantity of speech such as the number of utterances directed by the child to the adult experimenter, peers, or siblings (Barakova et al., 2015; Chung, 2019; Huskens et al., 2015). Chung (2019) evaluated the effects of a 12-week robot-mediated social skills intervention program on the social skills of children with ASD between the ages of 9 and 11 years. The results demonstrated that the children increased spontaneous verbal initiations with the adult instructor during the robot-mediated sessions. Another study has also reported increased quantity of vocal interactions with peers with ASD while a robot was present (Barakova et al., 2015). However, results are inconsistent with other studies reporting that children with ASD do not increase verbal initiation or responses with their typically developing (TD) siblings (Huskens et al., 2015). Therefore, increased speech from children with ASD during a robot-mediated intervention may depend on the role of the interaction partner, but additional research is needed to draw any conclusion.

Researchers have demonstrated that the quantity of child speech directed to robots during robot mediated interventions remain stable over time. For example, Tahir and colleagues (2018) examined the quantity of vocal interactions between children aged 6- to 15-years-old with ASD and a NAO robot. They found that child verbal interactions measured by the quantity of words, phrases, and questions did not significantly increase across sessions.

Even less is known about the quality of speech during robot-mediated social skills interventions. Most studies addressed the pragmatic function of speech produced by children (Albo-Canals et al., 2018; Barakova et al., 2015). Barakova and colleagues (2015) found that one child out of three pairs of children with ASD had significantly more “adequate” verbal responses to another child with ASD while the robot was present. However, an “adequate” response was only defined as needing to have “social meaning”. Albo-Canals and colleagues (2018) examined frequency of engagement between children with ASD and a robot during an intervention. One of the possible measures of engagement included the observation of speech quality, specifically, “asks questions actually pertaining to the activity.” While they did find an increase in engagement, speech quality as measured above was not further examined. Thus, the quality of speech to robots and peers with ASD requires further examination as little previous research has primarily focused on the quality of speech, especially to the robot, to our knowledge.

In the research literature, the quality of speech typically has been examined using the mean length of utterance (MLU; Schillingsburg et al., 2016; Yosick et al., 2016). In fact, it has been previously recommended as one measure of intervention outcomes for children with ASD (Tager-Flusberg et al., 2009). Previous research indicated children with ASD exhibit challenges in expanding the length of their utterances (Paul, 2008; Volden & Lord, 1991). For example, TD children were found to have higher MLUs than their age-matched peers with ASD (Volden & Lord, 1991). It is critical to improve MLU in speech of children with ASD as more complex speech is more socially acceptable and can convey more information (Yosick et al., 2016).

The aim of the current study is to examine both the quantity (speech rate) and quality (mean length of utterance) of speech from children with ASD to the NAO robot and to other peers with ASD during four sequential social intervention sessions. Based on previous research it is predicted that children with ASD will not increase their vocal interactions to the robot (Tahir et al., 2018), but will increase their vocal interaction with their peers with ASD (Barakova et al., 2015). Lastly, it is hypothesized that children's speech quality will remain stable across sessions during robot-child (Albo-Canals et al., 2018) and child-child interactions (Barakova et al., 2015).

2. METHOD

A. PARTICIPANTS

Six children (mean age = 11.6 years, SD = .73, range: 10.5-12.6 years) were recruited from the clinical population at the Norton Children's Autism Center, Louisville, KY which focuses on providing multidisciplinary support for children diagnosed with ASD and their families. Participants were invited to participate in 10 sessions (one session per week) if they met the following criteria: (a) chronological age range from 8 to 12 years old, (b) diagnosis of ASD, and (c) an IQ score of 65 or above. To assess for ASD, a trained clinical psychologist administered the Social Communication Questionnaire (SCQ; Rutter et al., 2003) and Autism Diagnostic Observation Schedule, Second Edition – Module 3 (ADOS-II; Lord et al., 2012). The SCQ is a measure of autism symptom severity with a cutoff score of 11 to indicate a high likelihood of an ASD diagnosis (Norris & Lecavalier, 2010). All participants received a score of at least 12 (range: 12 to 23). The ADOS-II assesses children's communication, social interaction, play and restricted and repetitive behaviors. Module 3 was administered because all the children were verbally fluent. The total score each child received at the end of the assessment was used by the clinician to help determine an ASD diagnosis. Participants' IQ scores were assessed using the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II; Wechsler, 2011). All participants met the minimum criteria of having an IQ score of 65 or above (M = 83.8, SD = 15.1, range = 65 to 103). Child 6 was excluded due to failure to participate in a majority of the sessions. Table 1 presents the demographic data and assessment scores for all participants. Prior to the experiment all children and their caregivers filled out their consent forms approved by the Internal Review Board at the University of Louisville. The caregivers and children were not paid for their participation.

Table 1. Child demographic and assessment scores.

Subj. #	Age (yrs)	Gender	FSIQ4	ADOS-II	SCQ
Child 1	10.5	M	89	12	12
Child 2	11.9	M	103	12	17
Child 3	11.5	M	74	16	15
Child 4	12.6	M	74	19	15
Child 5	11.3	M	98	12	23
Child 6	12.1	M	65	19	15
mean (SD)	11.6 (.73)		83.8 (15.1)	15 (3.2)	16.2 (3.5)

Note. SD = standard deviation; FSIQ4 = Full Scale IQ score obtained from the Wechsler Abbreviated Scale of Intelligence, Second Edition; ADOS-II = total score obtained from Autism Diagnostic Observation Schedule, Second Edition – Module 3; SCQ = scores obtained from the Social Communication Questionnaire.

B. MATERIALS

Robot. All children interacted with two identical, fully programmable, humanoid robots called NAO designed by Softbank Robotics (Softbank Robotics, 2021). These robots were distinguished only by color with one robot being red and the other orange. Figure 1 presents the pictures of the (a) red and (b) orange robots. The NAO robot is about 58 cm tall and has 25 degrees of freedom that allow for a variety of movements such as waving, walking, and head turning. Head turns from the robot were used as a proxy for eye gaze because the robot does not have eyes that move independently from its head. The robot was seated in a specially designed stand throughout the experiment for stability. Figure 2 presents the stand.

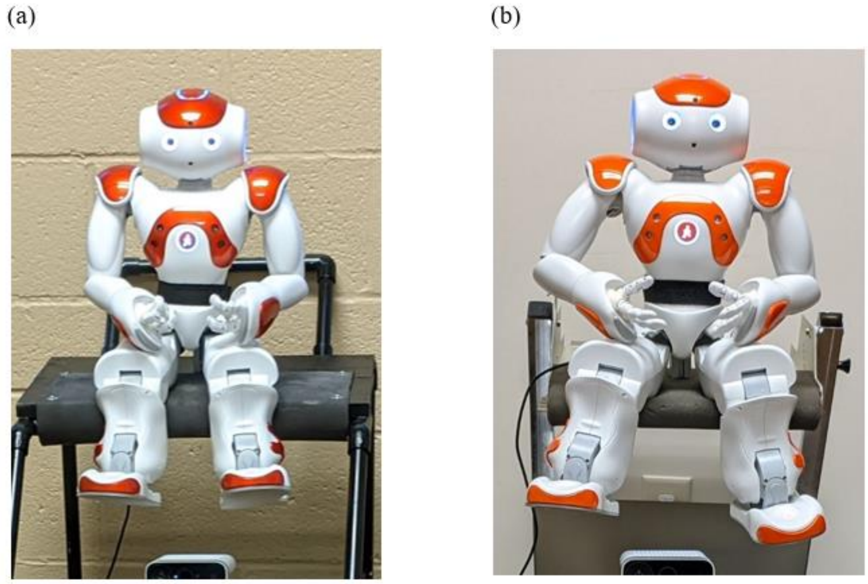

Figure 1. The visualization of the (a) red and (b) orange NAO robot.

Figure 2. The NAO robot seated in the specially designed stand.

Instructions and questions. All instructions and questions were provided to each child on a one-sided piece of paper. Instructions on how to interact with the robot were located at the top of the page. The five questions the children could ask the robot were located below the instructions.

C. SETTING AND EQUIPMENT

We conducted all sessions in the same two rooms. We placed the robot at the head of the room with three chairs in front. An adult was seated at the back of the room in a chair to observe the children and provide prompts if necessary (e.g., "(Participant's name), it's your turn") only after a set amount of time if the participant did not initiate on their own. To the far back right of the room a research assistant sat behind a table and laptop computer to monitor the robot. Three separate cameras faced each child to capture their interaction with the robot. All sessions were video and audio recorded using Flip UltraHD video camera designed by Cisco. Figure 3 shows the robot, children, and camera positions.

Figure 3. The layout of the room for the robot interaction.

D. PROCEDURE

The six children were divided into two groups, three children per group. Each group met in a separate room with a NAO robot (see Figure 3). Each child was asked to sit quietly in a chair until it was their turn to talk to the robot. Instructions and questions were provided to each child on paper that they held throughout each session. Instructions stated "Ask the robot a question from this page. You can pick any question. Wait for the robot to answer. The robot will also ask you a question. Make sure you answer the robot. Wait your turn before you pick your next question." Children sat in the same seat each session.

Each child initiated the conversation with the robot by asking one of five questions. All verbalizations and movements were programmed in a closed-loop approach. Once the robot recognized a question (e.g., "What do you like doing?"), it responded with an answer and repeated the same question back to the child (e.g., "I like movies. What do you like?"). The robot then listened while the child responded and finally acknowledged the child's response (e.g.., "Thanks for sharing."). Then, the next child initiated the conversation with the robot by asking one of the five questions. Consequently, each child had three turns to ask the robot a question in a one-on-one format.

E. ACOUSTIC ANALYSIS

In total there were eight recordings from four sessions. Audio files from each recording were extracted using Audacity (Audacity, 2021) as .wav files with 44.1 kHz sampling rate. These files were further analyzed using PRAAT 6.1.16 speech editor (Boersma & Weenink, 2021). The average duration of files in each session was 4.6 min. (*SD* = .46; range: 3.75-5.25). A total of 36.5 min. of audio were analyzed.

F. MEASURES

Utterances. Two types of events were coded: child and robot utterances. A combination of the waveform, spectrogram, and audio were used to manually identify the start and end of each utterance. An utterance was defined as "an independent clause and its modifiers that cannot be further divided without losing its essential meaning" (Miller & Iglesias, 1984). A single utterance was identified as a continuous speech sound with or without silent pauses of less than 300 ms originating from the same person. If a silent pause was greater than or equal to 300 ms then two separate utterances were coded (Gratier et al., 2015). All other non-linguistic noises were excluded (e.g., coughing, grunts, laughter). Adult utterances were excluded from the analysis since the providers role was only to instruct children on the child-robot interaction and adult-child interaction was not the focus of the therapy involving robots.

Utterance Directionality. The directionality of each utterance (e.g., whether the child addressed the robot or another child) was identified and coded using the participant's attentional focus from video recordings using facial/body direction, direction of eye contact, and physical movement (Hedenbro & Lidén, 2002).

Initiation and Responses. We identified whether the child initiated the interaction (e.g., the child asked the robot a question "What do you like doing?") or responded to a robot or child utterance (e.g., the robot asked a question and the child responded) using the child's focus of attention and semantic/pragmatic components of the utterance. Each utterance was coded as either an initiation or response.

Normalization procedure. To account for varying lengths in audio files, the number of utterances identified were normalized by calculating initiation rate and response rate. Overall speech rate was calculated as number of utterances per minute of recording disregarding whether it was an initiation or response.

Mean Length of Utterance. Mean length of utterance (MLU) was manually measured by identifying the number of morphemes in each utterance.

Reliability. From the eight recordings, two recordings were randomly selected. Each recording was coded by two undergraduate students who did not participate in the experiment. Each student coded the onset and the offset of the utterance and utterance directionality (see coding procedure described above). Inter-coder reliability (Pearson product-moment correlations) for the number of child utterances directed to the robot/other child was above 0.95.

MLU for two of the eight recordings were manually measured by two trained independent coders (one undergraduate and one graduate student) for all child utterances directed to the robot and other children. Inter-coder reliability (Pearson product-moment correlations) for the MLU of speech of the children was above 0.95.

G. STATISTICAL ANALYSIS

To examine children's speech rate, the rate of initiations and responses and MLU, Wilcoxon signed-rank tests were conducted using IBM SPSS Statistics 27 software (IBM Corp, 2017). We examine speech rate, the rate of initiations and responses and MLU for all sessions combined and across time by comparing sessions 1 vs. 2, 2 vs. 3, and 3 vs. 4. Only significant results are reported.

3. RESULTS

A. ROBOT-CHILD INTERACTION

Table 2 presents (a) overall speech rate (number of utterances per minute), initiation rate (number of initiations per minute), and response rate (number of responses per minute) and (b) MLU (number of morphemes per utterance) for all five children across four sessions during the child-robot interaction.

Table 2. Average Speech Rate and MLU for all Sessions in the Robot-Child Interaction.

Session #	Mean Speech Rate (number of utterances/min., sd)			MLU (number of morphemes per utterance, sd)		
	Overall Speech Rate (initiations + responses)	Initiation Rate	Response Rate	Overall MLU (initiations + responses)	Initiation MLU	Response MLU
1	2.53 (.58)	1.33 (.38)	1.16 (.44)	5.00 (.79)	5.78 (.55)	4.16 (1.38)
2	4.14 (2.74)	2.29 (1.40)	1.89 (1.43)	5.12 (1.27)	5.81 (.76)	4.42 (2.11)
3	2.97 (.64)	1.68 (.78)	1.29 (.40)	4.46 (.63)	5.23 (.47)	3.68 (1.43)
4	2.88 (1.01)	1.47 (.86)	1.4 (.24)	5.82 (1.60)	6.13 (1.27)	5.51 (2.12)
Mean (sd)	3.13 (.70)	1.69 (.42)	1.53 (.32)	5.10 (.56)	5.74 (.37)	4.44 (.78)

The results demonstrated that the children produced a marginally significant higher initiation rate in *Session 2* (*Mdn* = 2.22) than in *Session 1* (*Mdn* = 1.26), $Z = 1.75$, $p = .08$, $r = .78$, suggesting that the children addressed the robot more in *Session 2* than *Session 1*.

The results demonstrated that the children produced marginally higher MLU for initiations (*Mdn* = 5.67) than responses (*Mdn* = 4.94), $Z = -1.75$, $p = .08$, $r = .78$. Additionally, the results demonstrated that the children produced marginally higher MLU in *Session 4* (*Mdn* = 6.02) than *Session 3* (*Mdn* = 4.57), $Z = 1.75$, $p = .08$, $r = .78$. Finally, the results demonstrated that the children produced a significantly higher MLU for responses in *Session 4* (*Mdn* = 5.38) than *Session 3* (*Mdn* = 4.33), $Z = 2.02$, $p = .043$, $r = .91$. All other comparisons were nonsignificant.

B. CHILD-CHILD INTERACTION

Table 3 presents (a) overall speech rate (number of utterances per minute), initiation rate (number of initiations per minute), and response rate (number of responses per minute) and (b) MLU (number of morphemes per utterance) for all five children across four sessions during the child-child interaction.

Table 3. Average Speech Rate and MLU for all Sessions in the Child-Child Interaction.

Session #	Mean Speech Rate (number of utterances/min., sd)			MLU (number of morphemes per utterance, sd)		
	Overall Speech Rate (initiations + responses)	Initiation Rate	Response Rate	Overall MLU (initiations + responses)	Initiation MLU	Response MLU
1	0.21	0.21	0	5.50 (6.36)	11 (12.73)	0
2	1.33 (.77)	1.33 (.77)	0	2.67 (2.05)	5.33 (4.10)	0
3	1.13 (.29)	0.67 (.40)	0.63 (.45)	4.70 (1.15)	4.18 (.98)	5.08 (2.97)
4	1.38 (.91)	0.84 (.61)	0.54 (.47)	4.83 (2.38)	5.88 (2.19)	4.43 (1.93)
Mean (sd)	1.01 (.55)	0.76 (.46)	0.59 (.06)	4.43 (1.22)	6.60 (2.62)	4.76 (.46)

Note. No standard deviation if only one child produced one utterance.

All Wilcoxon's Signed Rank Sum tests were nonsignificant. These results suggest that there was no difference for speech rate, the rate of initiations and responses, and MLU for all sessions combined and across time.

4. DISCUSSION

In the current study, we examined whether the use of a NAO robot affects the quantity and the quality of speech in children with ASD who interacted with the robot and peers over time during a robot-mediated social skills intervention. Specifically, we examined child speech rate and MLU in overall vocal productions, initiations, and responses to the robot and the peers across four weekly sessions. In interactions with the robot, the results demonstrated no significant difference between sessions in children's overall speech rate or response rate to the robot. However, children produced a marginally higher initiation rate addressing the robot in *Session 2* compared to the *Session 1*. There was no overall difference between initiation and response rate. Across sessions there was a marginally higher MLU overall and significantly higher MLU for responses in *Session 4* compared to *Session 3*. But there was no difference in MLU for initiations across sessions. Children produced a marginally higher MLU in initiations than responses. Lastly, no significant differences in any measures were found in children's speech to their peers.

The results demonstrating that the children's speech rate to the robot remained similar over time is consistent with previous work examining speech from children with ASD to a robot (Albo-Canals et al., 2018; Tahir et al., 2018). Tahir and colleagues (2018) found that the amount of speech (measured by: number of words, phrases, or questions) from 6- to 15-year-old children directed to the robot over the course of 12 social skills intervention sessions remained the same. However, our results extend the Tahir and colleagues (2018) study by examining initiation and response rate during a different task (i.e., role-playing asking and answering questions with a robot). The marginally higher initiation rate in *Session 4* than *Session 3* identified in the current study suggest either a familiarity effect and/or an effect of the social skills intervention since they directed more speech to the robot despite the structured task where they were presented a set of questions they could ask the robot. However, the rate in which children answered the robot remained the same over time which suggests that children followed the predetermined instructions.

Previous research suggests that TD children decrease interaction with the robot overtime (Kanda et al., 2004). For example, Kanda and colleagues (2004) found that TD children aged 11 to 12 years old spent 3.33 minutes interacting with the robot during the first day, but at the end of the second week they spent less than a minute interacting with the robot. It is possible children with ASD do not lose as much interest in repeated stimuli as TD children as suggested by the results of our study since children with ASD require more time than their TD peers to habituate to social and non-social stimuli (Swartz et al., 2013; Vivanti et al., 2018).

The increase in the initiation rate is consistent with previous studies demonstrating that adolescents with ASD increased their ability to ask questions to an adult instructor during a social skills intervention over time (Dotson et al., 2010). However, in contrast to the findings of our study, the adolescents also increased their ability to answer questions from the adult instructor over time suggesting the effect of the social skills intervention (Dotson et al., 2010). While it is not possible to identify whether the increase in initiation rate was a result of the familiarity effect of the robot or the social skills intervention in the current study, future research needs to disambiguate between both explanations.

For the analysis of speech quality, the results demonstrated that the children's MLU was significantly longer by the last session when responding to the robot. This significant result likely affected the overall MLU that was found to be marginally longer by the time of the last session. Similar findings have been shown in research on a human-led intervention focusing on verbal initiation improvements for 6- to 12-year-old children with ASD (Mohammadzaheri et al., 2021). Indeed, the children participating in the targeted treatment program had a significant increase in their MLU from baseline to post-intervention two months later. Taken together, these results suggest that robot interventions may increase child MLU, similar to human-led interventions. Our finding is of particular interest as responses to the robot were not scripted. However, our results also suggest that children with ASD may need repeated exposure to the robot in robot-mediated social skills interventions before improvements in speech complexity are evident. This is an important finding that should be considered when designing the length of future robot-mediated social skills interventions with children with ASD.

Additionally, when children addressed the robot their MLU for initiations was marginally shorter than their responses, and children's overall MLU remained stable when addressing the robot overtime. These results are supported by findings of a study examining robot-directed speech to a robotic dog in a naturalistic setting (Kriz et al., 2009). The study found that adult males had significantly shorter requests compared to adult females addressing the same robotic dog (Kriz et al., 2009). Similarly, the difference in MLU between initiations and responses could be explained by the study methodology. The children were given a limited set of questions with which to address the robot, thus limiting their MLU when initiating the conversation. Therefore, future research should compare initiations and responses to a robot from children with ASD in a spontaneous, naturalistic setting.

The lack of any significant results in speech quantity and quality when children talked to each other also may be accounted for by study methodology. The present study employed a very structured group interaction with the robot where children were instructed to interacted with the robot in turn (i.e., only one person talks to the robot at a time) rather than talking to each other. Previous research using more naturalistic robot-child interactions in a group setting have found contrasting results. For example, children with ASD increased their vocal interactions with an adult instructor and ASD peers while a robot was present during a social skills intervention (Chung, 2019; Barakova et al., 2015). However, our results corroborate findings from Huskens and colleagues (2015) that reported no increase in initiations or responses from children with ASD to TD siblings. This is consistent with findings that adolescents make fewer social initiations to peers than TD adolescents (Dogget et al., 2013, Palman et al., 2008; Weiss & Harris et al., 2001). Thus, methodological design could be partly responsible for some of the contrasting findings.

5. CONCLUSION

The results of this study suggest that use of a NAO robot during a social skills intervention has had no effect on speech quantity (speech rate) but affected speech quality (MLU) of children with ASD who interacted with the robot. The results demonstrated that the children's overall speech rate to the robot remained the same over the course of four sessions and no difference between overall initiation and response rate. However, the study identified a marginally higher initiation rate in the later sessions while no changes in response rate were found. The children also produced a significantly higher MLU responding to the robot in later sessions, but not when addressing the robot. Children's MLU for initiations were marginally higher than MLU for responses to the robot and their overall MLU was marginally higher by the last session. Finally, no changes in speech rate or MLU in speech directed to peers with ASD were identified. These results suggest that robots, similar to human assistants, increase speech complexity in children with ASD. Limitations of the current study include the limited number of children who participated and the highly structured setting of the robot-child interaction. Therefore, future research needs to examine speech characteristics of children with ASD interacting with different members of their social environment including peers and clinicians in order to understand the contribution of humanoid robots on the development of child social skills during a naturalistic robot-mediated social skills intervention.

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