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The effect of a social robot mediator on speech characteristics of children with Autism Spectrum Disorder

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In the current investigation, we used a single case alternating treatments design to examine the effects of a robot prompter on the characteristics of vocal utterances in six children with autism spectrum disorder (ASD). Across two alternating conditions, robot prompting (RP) and no robot prompting (NRP) we measured participants mean length of utterances in morphemes (MLU) and the type-token ratio (TTR) as a degree of lexical variation. Our findings demonstrated that children who produced a high overall MLU demonstrated a decreased MLU in the RP condition compared to the NRP condition. Children who produced a low overall MLU had a higher MLU in the RP compared to the NRP condition. No differences in children's TTR during RP and NRP conditions were found. The results suggest that the use of a social robot prompter positively affects the morphosyntactic complexity of speech in children with ASD, however, large individual variability was observed.

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1. INTRODUCTION

Autism spectrum disorder (ASD) is a developmental disorder characterized by challenges in social interactions (American Psychiatric Association, 2013). Its cardinal features include deficits in language and social communication as well as the presence of restricted repetitive behaviors (American Psychiatric Association, 2013). Due to these deficits, students with ASD may have reduced peer interactions, more social isolation, and experience more bullying (Bauminger et al., 2003; Cappadocia et al., 2012; Humphrey & Symes, 2011). In addition, ASD can cause deleterious impacts on post-secondary outcomes such as employment, independent living, and community participation (Nasamran et al., 2017; Song et al., 2021).

Given the negative effects of ASD on student language and social communication, researchers have proposed numerous interventions to improve outcomes for this population (Kamps et al., 2014; Kamps et al., 2015; Steinbrenner et al., 2020). For example, peer-mediated interventions that combine adult facilitation with social learning opportunities among peers have been demonstrated to improve social and communication skills in learners with ASD including language growth and increased initiations towards peers. More recently, researchers have advanced technology-assisted instruction (TAI) for improving social-communication skills in individuals with ASD. Technology-assisted instruction centers technology as the main instructional feature that supports the learning and performance of the student (Steinbrenner et al., 2020). The purpose of the current pilot study was to explore the effects of an autonomous robot change agent on the conversational skills of six children with ASD. It served a part of a project funded by the National Science Foundation to develop and evaluate a range of technologies for improving outcomes for children with ASD.

Social robot assisted instruction falls under the broader category of TAI and has garnered greater interest as an intervention due to its broad applicability and reported positive outcomes for students with ASD (Boccanfuso et al., 2017; Cabibihan et al., 2013; Fachantidis et al., 2020; Kim et al., 2013). A subfield of social robotics has emerged in which interventionists use robots to facilitate engagement. Recent research findings have indicated that social robots have the potential to increase social interactions, and improve communication and emotional skills in students with ASD (Boccanfuso et al., 2017; Fachantidis et al., 2020; Kim et al., 2013). In addition, these social robots can be used as to assist clinicians with ASD diagnoses, as social mediators between the child and therapist, or even as playmates for children with ASD (Cabibihan et al., 2013). Robot-assisted instruction may be specifically beneficial for children with ASD because robots are less complex than humans, provide less sensory stimulation, and may be less intimidating than people (Cabibihan et al., 2013).

Researchers have demonstrated that social robots can assist with the development of linguistic skills in pediatric populations diagnosed with ASD who usually demonstrate deficits in a number of linguistic domains including limited attention to speech, reduced rates of communication, deficits in prosody, echolalia, as well as a number of deficits in pragmatic characteristics of the language (e.g. turn-taking skills, managing discourse topics, using inappropriate style of speech to fit conversation partners and settings, and having trouble inferring what information is relevant or interesting to others) (Paul, 2008). Studies have shown that the use of social robots increases the quantity of speech and the vocal turn-taking in children with ASD (Boccanfuso et al., 2017; Kim et al., 2013; Pennington et al., in press) suggesting an effect of the therapy on the pragmatic use of language. For example, Kim and colleagues (2013) demonstrated that 4- to 12-year-old children with ASD spoke more and directed more speech to the adult when the interacting partner was a robot as compared to a human or computer game interaction partner. Similarly, Boccanfuso et al. (2017) demonstrated an increase in mean length of spontaneous utterances and receptive language skills in 3- to 6-year old children reflecting the child's ability to comprehend language, playing a critical role in effective social interaction during robot-assisted therapy. A recent study by Pennington and colleagues (in press) investigating the effects of a robot prompter on the amount of social interaction among three pairs of 11-year-old children with ASD indicated that participants produced more utterances and conversational turns when a robot prompter was present. In addition, researchers reported large variability on measured outcomes across participants (Kim et al., 2013; Pennington et al., in press).

Although research findings suggest that the use of social robots increases the *quantity of speech* and the amount of vocal turn-taking (Boccanfuso et al., 2017; Kim et al., 2013; Pennington et al., in press), there is a gap in our knowledge whether the *quality of speech* in children with ASD is affected by this type of therapy. One of the characteristics of the *quality* of speech is lexical diversity and morphosyntactic complexity. Lexical diversity is related to children's productive vocabulary and stages of language development; morphosyntactic complexity is related to children's grammatical development as reflected by morpheme (Brown, 1973). Research suggests that children with ASD have deficits in lexical diversity and morphosyntactic complexity compared to typically developing (TD) children (Boucher, 2012; Eigsti et al., 2007). Therefore, it is necessary to investigate whether robot assisted therapy affects these characteristics that are commonly used to measure dynamic language progress in children with ASD (Tager-Flusberg et al., 2009).

Lexical diversity and morphosyntactic complexity are reflected by morpheme usage (Brown, 1973). Such measures as Mean Length of Utterances in morphemes (MLU) and Type Token Ratio (TTR) have been widely used to assess the average number of morphemes per utterance (MLU) (Gabig, 2021) and the degree of lexical variation defined as the total number of unique words over total words in each utterance (TTR) (Yang et al., 2022). Studies examining MLU and TTR in children with ASD have demonstrated mixed results. Some researchers have found that children with ASD produce shorter utterances with fewer grammatical morphemes, thus exhibiting a lower MLU, than their TD peers (Eigsti et al., 2007; Gabig, 2021; Salem et al., 2021). Other study findings have shown that children with ASD followed the same developmental pattern as TD children demonstrating similar MLU (Tager-Flusberg et al., 1990). Similarly, studies have demonstrated no difference in TTR measures between children with ASD and TD peers (Goodkind et al., 2018; Kelley et al., 2006; Suh et al., 2014). However, other studies have shown that children with ASD displayed a slightly higher TTR than chronologically age matched neurotypical peers (Cola et al., 2022; Eigsti et al., 2007). In summary, these mixed results on MLU and TTR measures might reflect the different impacts of child age, stage of development, as well as the individual level of support needs (Kjelgaard & Tager-Flusberg, 2001; Naigles et al., 2011; Suh et al., 2014; Tek et al., 2014).

The aim of the current study is to examine whether the use of a social NAO robot as a mediator affects the MLU and TTR in 10- to 11-year-old children with ASD. This research was conducted as part of a National Science Foundation-funded initiative to develop and evaluate a variety of technologies for enhancing outcomes for children with ASD. This study extends existing knowledge in two domains. First, a robot-assisted intervention was implemented in the absence of a human instructor. The robot was programmed to detect absences in the students' conversation and then provide content-related prompts to facilitate conversation (e.g., *What is your favorite subject in school*, *Tell each other about something that made you smile today*). Second, it is possible that the use of a social NAO robot may increase MLU and TTR measures that reflect morphosyntactic skills in children with ASD (Boucher, 2012; Brown, 1973; Eigsti et al., 2007; Gabig, 2021; Yang et al., 2022). Assuming efficacy is demonstrated, autonomous robot change agents might have the potential to facilitate student interactions in various settings, including schools, if and when an adult interlocutor may not be present.

2. METHODS

A. PARTICIPANTS

Six male school-aged children (M = 11.4 years, SD = 0.86, range: 10.4-11.9 years) were recruited from an autism center affiliated with the University of Louisville, focused on providing care for children diagnosed with ASD. Participants were asked to join providing they satisfied the following criteria: (a) chronological age range of 8 to 12 years; (b) a diagnosis of ASD based on Diagnostic Statistical Manual 5th edition (*Diagnostic and statistical manual of mental disorders: DSM-5™, 5th ed*, 2013); (c) were not reported to have an intellectual handicap; and (d) used vocal communication to engage in interactions with others. Clinicians characterized the participants as having challenges with social skill performance, particularly managing conversations. Participants were randomly assigned to three child-child dyads for additional testing. The same children were included in each dyad for all sessions. Participants and their guardians filled out consent forms approved by the University's Internal Review Board prior to the experiment. The caregivers and children were not paid for their participation.

B. SETTING AND EQUIPMENT

All of the sessions were held at a university-affiliated autism facility. Each pair was assigned one of three therapy rooms with a table, two chairs, and cabinets. Participants were seated exactly opposite one another. During robot prompting (RP) sessions, the robot was positioned at one end of the table, facing the participants while forming a triangulated position. The beginning of the session was defined as the time that the experimenter left the room, and the end of the session was defined as the time that the experimenter returned to the room. Three sides of the room were outfitted with two Flip Ultra HD digital video cameras and an iPad for audio-visual recording under all circumstances. Before each session, the researcher entered the room, activated the cameras, and left. The cameras captured the meetings but did not transmit video outside the room. During RP sessions, a SoftBank Robotics H25 NAO robot was utilized. NAO is a humanoid robot created for human-robot interactive tasks. Each NAO robot measured 57 cm in height, weighed 5.4 kg, and had 25 degrees of freedom (DOF) between the head, two arms, two hands, three fingers on each hand, pelvis, and two legs. The robot interacted wirelessly with a Dell Inspiron N4110 laptop equipped with a Western Digital solid-state drive (SSD) in place of a traditional hard drive. The Linux operating system and Choregraphe software (Softbank Robotics, 2021) on the laptop were used to program the robot. The NAO robot behaved autonomously according to a pre-programmed set of behaviors for listening, providing a prompt, and animating while prompting.

C. PROCEDURE

Each of the three child-child dyads completed 10 to 12 sessions lasting 5-10 min with their order counterbalanced. The sessions occurred in either Robot Prompting (RP) or No Robot Prompting (NRP) conditions. Prior to each RP sessions, researchers entered the room and asked the participants to talk to each other, not touch the robot, and remain seated during the session. The researcher explained to the participants that the robot would produce prompts but not respond to questions or interactions directed from the participant to the robot. Subsequently, the researcher left the room and started the session. During the RP condition, the robot produced a prompt (a) if both participants were silent for more than 30 s or (b) if one subject was dominating the conversation by producing speech continuously for more than 1 min while the other subject was silent. The robot emitted one of 53 randomly selected vocal prompts (e.g., “Talk about your favorite subjects in school.”) and did not repeat the same prompt within a session across the duration of the study. If the prompt was emitted in response to one subject producing continuous speech, it was preceded by the participants’ names and a brief reminder about the directions of the activity (e.g., Andrew and Charles, make sure you both share. Tell each other about your favorite holiday.) The researchers sat in an adjacent room with no direct visual access to participants but used the Choregraphe software to indirectly observe whether the robot’s position was altered by participants. The participants did not disrupt the robot at any time during sessions. At the end of each session, the researcher re-entered the room and delivered general praise to the participants. Prior to NRP sessions, a researcher entered the room and vocally directed the participants to talk to each other and remain in their seats during the session. Then, the researcher left the room and started the session. At the end of each session, the researcher re-entered the room and delivered general praise to the participants.

D. ANALYSIS OF RECORDINGS AND MEASURES

Dyads 1 (AC) and 3 (WD) participated in 10 sessions, while Dyad 2 (MH) participated in 12 sessions. Dyad 1 produced in total 512 utterances across all sessions, Dyad 2 produced in total 1041 utterances, and Dyad 3 produced 884. On average, weekly sessions lasted 8.57 minutes (SD = 1.11) each. An independent-samples t-test demonstrated no difference in the duration of sessions between Robot (M = 8.71 minutes, SD = 1) and No Robot (M = 8.44 minutes, SD = 1.24) conditions, t (30) = 2.04, p = 0.5.

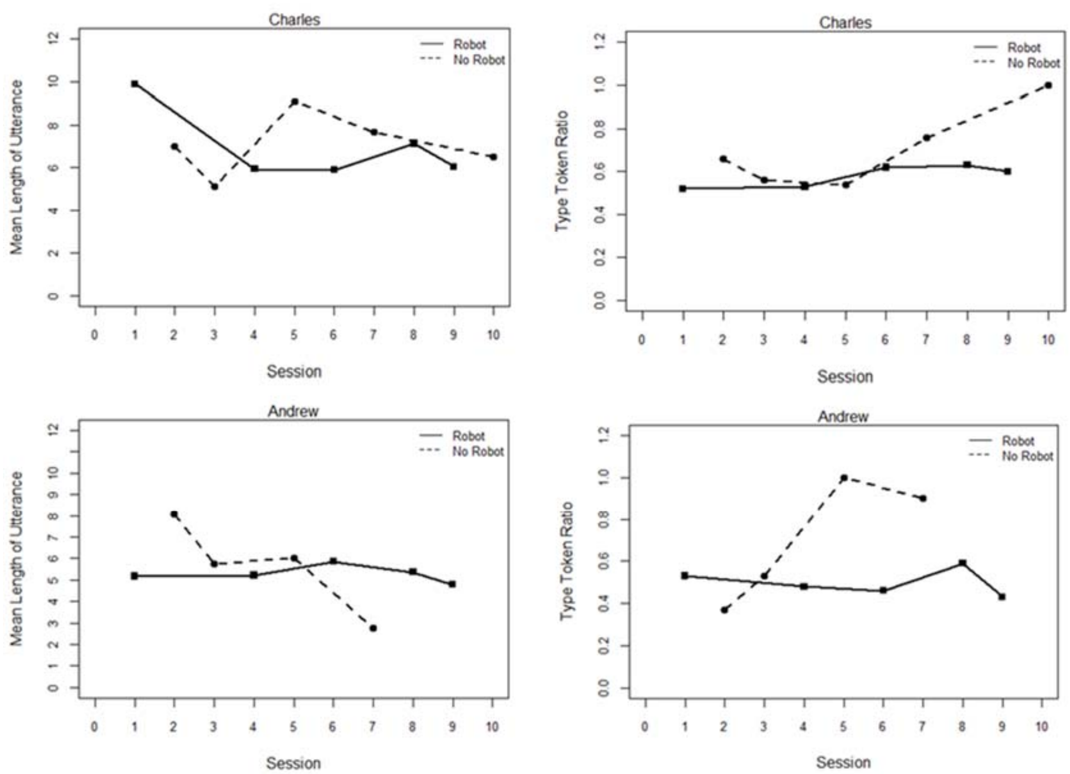
The language sample analysis approach (LSA) was used to assess each child's language production and to track the accompanying change for each condition (Miller et al., 2016; Schmidt et al., 2017). The Systematic Analysis of Language Transcripts (Miller & Iglesias, 2012) software package was used to facilitate the transcription of the video probes. The transcripts were analyzed by using SALT’s built-in “Standard Measures” analysis feature. The following measures were collected for each utterance using SALT software.

Mean Length of Utterances (MLU). MLU was calculated for each child utterance. MLU was defined as the number of morphemes per utterance (Gabig, 2021).

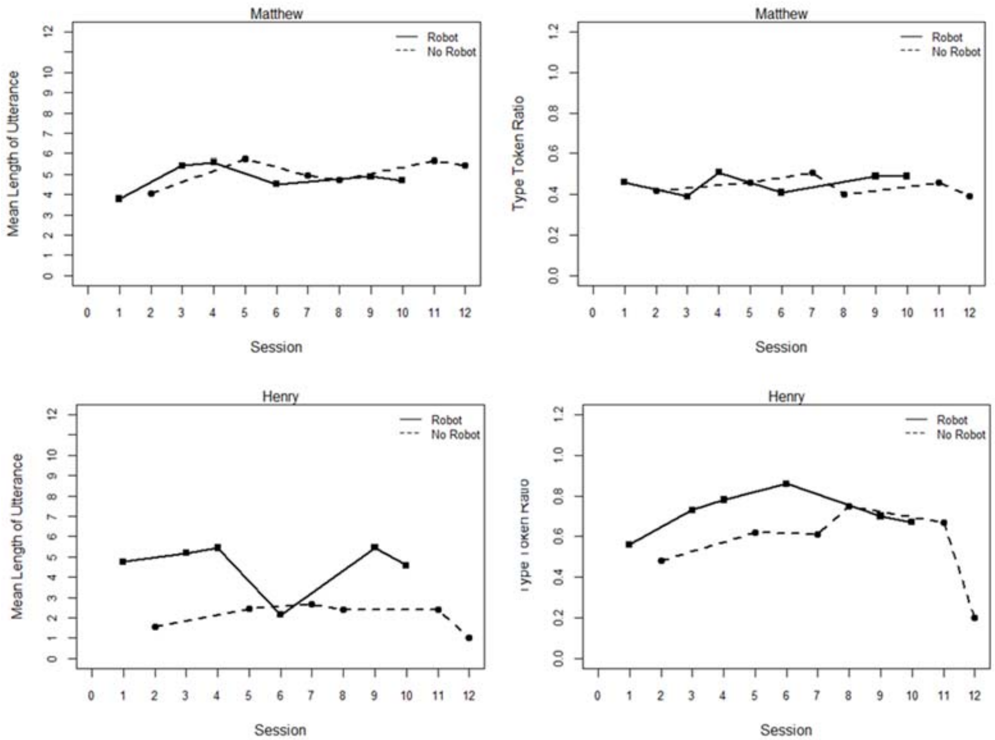
Type-Token Ratio (TTR). TTR was calculated for each child utterance. TTR was defined as the total number of unique words (types) divided by the total number of words (tokens) in each utterance (Yang et al., 2022).

3. RESULTS

(a)



(b)



(c)

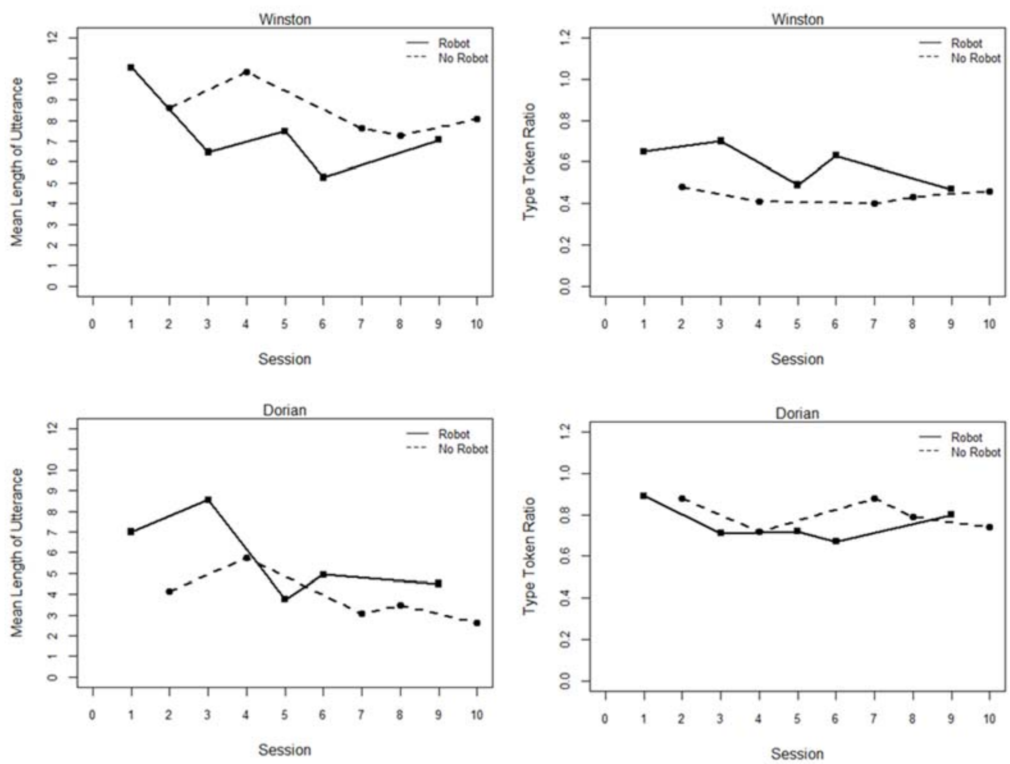


Figure 1 shows MLU and TTR in (a) Dyad 1, (b) Dyad 2, and (c) Dyad 3 in Robot and No Robot Conditions across sessions.

Dyad 1: Charles and Andrew

MLU. In the RP condition, Charles produced on average 7 (*SD* = 1.7) morphemes per utterance and Andrew produced on average 5.3 (*SD* = 0.4) morphemes per utterance. In the NRP condition, Charles produced on average 7.1 (*SD* = 1.5) morphemes per utterance and Andrew produced on average 4.5 (*SD* = 3.2) morphemes per utterance. These results indicate that Charles had a higher MLU than Andrew in both RP and NRP conditions. Charles demonstrated no difference in MLU between RP and NRP condition. Andrew demonstrated a slightly higher MLU for RP compared to NRP sessions. Across sessions, in the RP condition, Charles exhibited an initial decrease in the MLU but then remained stable. Andrew on the other hand, demonstrated a stable MLU across all RP sessions. In the NRP condition, Charles increased MLU by Session 5 but decreased MLU by Session 10. Andrew, however, demonstrated a steady decrease across all NRP sessions.

TTR. In the RP condition, Charles's average TTR was 0.6 (*SD* = 0.1) and Andrew's was 0.5 (*SD* = 0.1). In the NRP condition, Charles's average TTR was 0.7 (*SD* = 0.2) while Andrew's was 0.6 (*SD* = 0.4). These results suggest similar TTRs in both children during the RP and NRP sessions. Further, both Charles and Andrew showed a stable TTR throughout all RP sessions. In the NRP condition, TTR increased steadily for Charles and initially increased, then decreased for Andrew.

Robot Prompts. In sum, the robot produced 29 prompts in the RP condition with the average MLU 9.3 morphemes per utterance (*SD* = 1.7) and the average TTR 0.7 (*SD* = 0.1).

Dyad 2: Matthew and Henry

MLU. In the RP condition, Matthew produced on average 4.8 (*SD* = 0.7) morphemes per utterance and Henry produced on average 4.6 (*SD* = 1.3) morphemes per utterance. In the NRP condition, Matthew produced on average 5.1 (*SD* = 0.7) morphemes per utterance and Henry produced on average 2.1 (*SD* = 0.7) morphemes per utterance. These results suggest that Matthew had a higher MLU than Henry in both RP and NRP conditions. Matthew demonstrated no difference in MLU between RP and NRP sessions. Henry exhibited a higher MLU in the RP sessions compared to NRP. Across sessions, in the RP condition, Matthew exhibited a stable MLU across all sessions. Henry on the other hand, demonstrated an initially stable MLU but had a rapid drop in the 6th session followed by a sharp increase. In the NRP condition, both Matthew and Henry exhibited a stable MLU.

TTR. In the RP condition, Matthew's TTR was, on average, 0.5 (*SD* = 0.05) and Henry's was 0.7 (*SD* = 0.1) TTR. In the NRP condition, Matthew's TTR was 0.4 (*SD* = 0.05) while Henry's was 0.6 (*SD* = 0.2). Henry had a higher TTR than Matthew in both the RP and NRP sessions. Further, both Matthew and Henry showed a stable TTR throughout all RP sessions. Matthew exhibited a similar stability in TTR in NRP sessions. For Henry, in the NRP condition, TTR remained initially stable but then rapidly dropped off in the 12th session.

Robot Prompts. In sum, the robot produced 50 prompts in the RP condition with the average MLU 9.5 morphemes per utterance (*SD* = 0.7) and the average TTR 0.6 (*SD* = 0.1).

Dyad 3: Winston and Dorian

MLU. In the RP condition, Winston produced on average 7.4 (*SD* = 2.0) morphemes per utterance and Dorian produced on average 5.7 (*SD* = 2.0) morphemes per utterance. In the NRP condition, Winston produced on average 8.4 (*SD* = 1.2) morphemes per utterance and Dorian produced on average 3.8 (*SD* = 1.2) morphemes per utterance. These results suggest that Winston had a higher MLU than Dorian in both RP and NRP conditions. Winston demonstrated a lower MLU in the RP sessions. Dorian demonstrated a higher MLU in the RP sessions. Across RP sessions, Winston exhibited an initial decrease in MLU followed by stable results in following sessions. Dorian on the other hand, demonstrated an initial increase in MLU followed by a rapid drop in the 5th session; the remaining sessions had a stable MLU. In the NRP condition, both Winston and Dorian showed an initial increase, then decrease in MLU, but then stabilized in the remaining sessions.

TTR. In the RP condition, Winston's average TTR was 0.6 (*SD* = 0.1) and Dorian's was 0.8 (*SD* = 0.1). In the NRP condition, Winston's average TTR was 0.4 (*SD* = 0.03) while Dorian's was 0.8 (*SD* = 0.1). These results suggest that Dorian had a higher TTR than Winston in both the RP and NRP sessions. Across

RP sessions, Winston's performance showed minimal variability with a slight decreasing trend over time. Dorian's performance remained stable in TTR with minimal change. In the NRP sessions, both Winston and Dorian had a stable TTR.

Robot Prompts. In sum, the robot produced 43 prompts in the RP condition with the average MLU 9.7 morphemes per utterance (*SD* = 1.5) and the average TTR 0.6 (*SD* = 0.1).

4. DISCUSSION

In the current study, we examined whether the use of a social NAO robot as a mediator would affect the lexical diversity expressed as MLU and TTR measures in 10- to 11-year-old children with ASD. Overall, our findings suggest differences amongst participants in their responses to RP and NRP conditions in MLU measures. Children who produced a high MLU overall demonstrated a decreased MLU in the RP condition compared to the NRP condition. On the other hand, children who produced a low overall MLU had a higher MLU in the RP compared to the NRP condition. Interestingly, our findings indicated no differences in children's total number of unique words in each utterance during RP and NRP conditions, despite individual differences in their TTR measures. For example, in Dyad 1, there were no differences in TTR measures between participants. However, in Dyads 2 and 3, one child (Henry and Dorian) produced a higher TTR compared to the other child (Matthew and Winston). In addition, children in each dyad demonstrated similar TTRs in the RP conditions compared to the NRP conditions suggesting that there was no effect of social robot use on TTRs. Across sessions, results were mixed. In general, performance was stable in Dyads 2 and 3. In Dyad 1, however, even though participants seemed to lose interest in conversing with one another, the robot could have mediated verbal engagement when interest in the communicative partner diminished.

Researchers have suggested that the use of social robots may increase the *quantity of speech* and the amount of vocal turn-taking (Boccanfuso et al., 2017; Kim et al., 2013; Pennington et al., in press). Specifically, these findings indicated that there was greater child interest in a social robot, and that the robot facilitated social interactions, engagement, and promotion of child-robot activities to child-other activities through robot prompting and robot tasks (Boccanfuso et al., 2017; Kim et al., 2013). The current study has extended previous results by demonstrating that the *quality of speech*, specifically its morphosyntactic characteristics, is affected by the use of a social robot. The two most frequently derived indices to examine speaker's lexical (vocabulary) richness are MLU (Brown, 1973) and the TTR (Templin, 1957). Children with ASD have been shown to produce a low MLU compared to TD peers indicating reduced grammatical complexity (Eigsti et al., 2007; Gabig, 2021; Salem et al., 2021). Studies on TTR measures have been more mixed, demonstrating that children with ASD produce either a slightly higher TTR (Cola et al., 2022; Eigsti et al., 2007) and or no difference in TTR measures (Goodkind et al., 2018; Kelley et al., 2006; Suh et al., 2014) compared to TD peers. Therefore, the results of the current study suggest that the use of a social robot prompter may increase the lexical diversity in children with ASD, as measured by MLU but not TTR measures. It is possible that the lack of effect of the social robot prompter on TTR can be accounted for by a limited dataset since this measure is significantly impacted by sample size, with small samples potentially showing excellent diversity simply as a function of few tokens (Miller, 1981; Templin, 1957; Yang et al., 2022). Thus, future research that includes a larger sample size of children producing at last 100 words or 100 utterances (Charest et al., 2020; Watkins et al., 1995) is warranted in order to identify an effect of a social robot prompter on TTR measures.

The results of the study have also demonstrated that the use of a social robot prompter had a positive impact on the amount of MLU in the children who produced a lower MLU overall when compared to the other child (with high MLU). These results suggest that the robot might suppress responsiveness for children with high MLU to allow low MLU children to speak more. Furthermore, the use of a social robot prompter may affect conversational adaptation in children with ASD. Conversational adaptation is defined as a process by which individuals alter their communicative behaviors in response to cues produced by a conversation partner; for example, the amount of language (talkativeness) with an interested versus bored partner (Borrie et al., 2019; Cola et al., 2022; McNaughton & Redcay, 2020; Pickering & Garrod, 2006). Research has demonstrated the social benefits of conversational adaptation in neurotypical adults. TD children demonstrate precursors of social adaptation, for example turn-taking and pitch adjustment in response to parental voices, early in their development (Feldman et al., 2011; Harbison et al., 2018).

However, conversational adaptation poses a significant challenge for children with ASD (Dolan et al., 2016; Feldstein et al., 1982; Grossman & Tager-Flusberg, 2008). For example, some autistic adults engage in monologuing while others are overly reticent in allowing others to take over a conversation (Adams et al., 2002). Similarly, recent research also has demonstrated that children with ASD do not adapt their conversational contributions in response to their partner's behavior (i.e., speaking more when their conversational partners were interested, and speaking less when their partners were bored) (Cola et al., 2022). It is possible that the use of a social robot as a prompter positively affects conversational adaptation in children with ASD that constitutes one of the possible directions of the research in our laboratory.

Finally, the study has failed to demonstrate that the use of a social robot prompter increased participants' verbal engagement since all dyads have shown a relatively stable MLU and/or TTR trajectory. However, Andrew, the child in the first dyad, decreased considerably his MLU and TTR in the NRP compared to the RP condition (Figure 1(a)). Similarly, Henry, the child in the second dyad (Figure 1 (b)) and Dorian, the child in the third dyad (Figure 1 (c)) have demonstrated some decrease in MLU and/or TTR measures in the NPR condition towards the end of the experiment. Previous research on the use of social robots for autism therapy suggests that children with ASD remained relatively engaged (as measured by a combination of non-verbal and verbal scores) when interacting with the robot over a prolonged period of time (Rakhymbayeva et al., 2021; van Otterdijk et al., 2020). However, no significant increase in the engagement rate over a period of 10 sessions was identified (Rakhymbayeva et al., 2021). Thus, the results of the current study are consistent with previous research examining the familiarity and novelty effect of the use of the social robot on child engagement (Rakhymbayeva et al., 2021; van Otterdijk et al., 2020) but extend the findings to include child verbal behavior (MLU and TTR measures) in the presence of the social robot prompter. Since the current project was conducted within a larger scale National Science Foundation study identifying the robot function for long-term use in the absence of a human instructor (e.g. in a hospital waiting room), future research examining the characteristics of long-term verbal and non-verbal interaction between children with ASD and a social robot is warranted given that such relationships may change over time (Rakhymbayeva et al., 2021; Torta et al., 2014).

5. CONCLUSIONS

The field of social robotics exhibits considerable potential in the domain of intervention for students diagnosed with ASD and other developmental disabilities. The present study expands upon the existing body of knowledge by illustrating that social robot prompters can positively impact the quality of speech in children with ASD. These findings suggest that the lexical diversity, as measured specifically by MLU, and conversational adaptation may be beneficially affected in children with ASD. However, the current study was limited by its small sample size, and the fact that participants were not matched in their individual stages of linguistic ability. Furthermore, the sessions were limited in duration, and should be lengthened in the future to gather more utterances since MLU depends on the number of utterances produced. In the future, the use of social robots in both school based, and therapeutic settings have the potential to increase the vocabulary richness of children with ASD, and, ultimately, positively affect their language development.

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