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Talk to me: The role of human-robot interaction in improving verbal communication skills in students with Autism or Intellectual Disability

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Abstract— **Autism is a developmental condition that can cause significant social, communication, and behavioral challenges. Children on the autism spectrum may have difficulties developing verbal communication skills, understanding what others say, or communicating through non-verbal cues. Similar difficulties are experienced by children with developmental delay. A recent trend in robotics is the design and implementation of robots to assist during therapy and education of children with learning difficulties. Although encouraging results suggests that robots can be beneficial, there has been limited work on the long-term impact of these tools on the verbal communication skills of children with autism or developmental delay. This paper explores the impact of robots on the verbal communication skills of secondary aged students with moderate to severe intellectual disabilities and autism. A qualitative study was carried out, via focus groups and interviews with parents, carers and staff members, 24 months after the introduction of two humanoid robots into the disability unit of a public secondary school. Results show that humanoid robots can provide benefits in articulation, verbal participation and spontaneous conversation in these young adults. Three exemplars are presented.**

I. INTRODUCTION

Autism spectrum disorder (ASD) is an ongoing neurodevelopmental condition that results in deficits in communication, social interaction and behavior. The degree of the impairments related to ASD varies significantly across a spectrum, ranging from severe to near-typical social functioning. For some, there can be significant impacts on quality of life [1]. In 2012, there were 115,400 Australians diagnosed with autism, and over 600,000 with an intellectual disability [2]. There is some overlap in these figures. Bourke et al. [3] observed that approximately 70% of children with ASD had mild to moderate intellectual disability (ID). The majority of them (over 60%) had severe limitations in communication, mobility or self-care. On completing school, young people with ID and/or autism are less likely to move into the labor force than their mainstream peers. Deficits in communication are a primary barrier to workforce participation [4].

Speech and language deficits are evident in early childhood, and form one of the key diagnostic criteria for autism [5]. Almost 50% of children on the autism spectrum present with insufficient spoken language for effective communication [6], with many never developing functional speech. Some will use non-verbal means to express their needs, while others will speak in phrases or sentences that have little-to-no meaning to others [7]. When present, verbal communication might be characterized by repetitive or idiosyncratic speech. Additionally, many autistic children possess high levels of social anxiety, lack of spontaneity or have difficulty initiating verbal and non-verbal communication with others, making interpersonal communication challenging.

For over a decade, researchers have explored the use of socially-assistive robots (SARs) to supplement traditional education for autistic children [8]. Autonomous and remotely-operated robots have shown that SARs can promote, among other skills, facial expression recognition [9], shared attention [10], imitative free-form play [11], and turn taking [12]. The most effective approaches to date, are those that use robots in free or semi-structured interactions [13–15].

When it comes to intervention in ASD or ID, the main goal of SARs has been the development of social and communication skills. However, the majority of the work has focused on the development of non-verbal communication skills such as eye contact and turn-taking [16]. There is no solid evidence on the long-term benefits of SARs on the verbal communication skills of this population.

This paper reports on a qualitative study implemented using focus groups and semi-structured interviews, 24 months after the introduction of two humanoid robots into the disability unit of a public secondary school located in regional South Australia. Particular attention is given to the capabilities of the robots in assisting students to improve their verbal communication skills. Our results suggest that humanoid robots are particularly beneficial for students with at least a basic level of verbality, and can provide benefits in articulation, verbal participation and spontaneous conversation. Details of three case studies are presented. This report expands our previous work where we described the potential of SARs to support autistic students with their academic learning, daily living and social skills [17].

II. VERBAL COMMUNICATION IN ASD

Language and communication are both related and complementary parts of an integrated social interaction system. Language entails a complex system of symbols expressed through speech, writing or signs (sign language). Communication, on the other hand, is the act of conveying messages to interactive partners through a combination of modalities including gaze, facial expression, body movement and voice intonation. Communication can be verbal or non-verbal.

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Autistic individuals have varying degrees of difficulty acquiring speech and language. However, impairments in social communication is one of the core deficits used to determine a diagnosis of autism [5]. Common communication impairments include abnormal eye contact, the inadequate use of gestures or facial expressions, developmental delays in spoken language, the inability to initiate or maintain a conversation, and unusual use of verbal behaviors, such as echolalia – the repetition of another person's spoken words. Common deficits in conversational skills include difficulty managing turn-taking, inappropriate use of speech to fit conversation context, inappropriate use of eye contact and other non-verbal behaviors, and trouble inferring what information is relevant to conversation partners [18].

Without intervention, communication deficits can persist across the lifespan, hampering social and economic participation. As a result, a number of interventions have been proposed and trialed. There is some concern that augmentative and alternative communication (AAC) interventions, such as finger spelling or the use of the Picture Exchange Communication System (PECS), could interfere with natural speech production [19]. A systematic review of 11 studies found that while AAC interventions did not impede speech production, only modest benefits were gained [20]. Similarly, a review of computer-based interventions showed promise, but again, only small effect sizes [21]. A recent review of evidence-based practices strongly suggests a combination of approaches, tailored to the individual and the stage of development, is likely to be most effective [22]. Given the attraction of technology to children with an ASD diagnosis, it is very likely that technology-based interventions will play a significant role.

III. ASSISTIVE TECHNOLOGY IN AUTISTIC CHILDREN

It is well known that children on the autism spectrum enjoy playing with computers and mechanical devices. Mainstream technologies—including apps, computer games and virtual reality devices—are commonly used to facilitate interpersonal communication for this population [23–25]. These technologies offer safe, realistic-looking scenarios that can be built to depict everyday social situations, providing an environment that allows for self-paced learning and immediate feedback, while minimizing the need for 'real world' social interactions during the learning process, a common source of anxiety for many people on the autism spectrum [26].

It is often believed that by using first-person, realistic-looking, computer-generated environments, autistic students can develop a functional range of daily living skills (e.g. social and communication skills) that would increase their opportunities for a more independent life [27–30]. It has been argued that the realism of computer simulated environments, as well as the increased sense of presence provided by immersive virtual environments, can help promote learning and increase the probability that a person would generalize newly learned skills into everyday living [30, 31].

Although these technologies appear to be effective, a significant concern is that the large gap between the safe and structured environment of computer-based interventions and real world social behavior may result in poor transfer of skills to real world interactions [23].

Over the last decade, researchers have explored the use of social robots as tools to supplement traditional therapy and education [8]. These robots are often presented as toys. These 'toys' are novel, animated, are (or appear) autonomous, and set themselves apart from traditional toys, thereby further maintaining a child's interest. The three-dimensional embodiment of robots, furthermore, provides a compromise between the virtual world—available through digital technologies—and the real world, by promoting a full embodied experience on the part of the child. A robot can provide complex behavior patterns, such as those available in interpersonal interactions, and evoke social behaviors and perceptions in the people they interact with, while appearing less intimidating and more predictable than humans [32].

There are a number of potential uses for social robots in therapy and education of young people with autism. In assessment, for example, a protocol to assist during the diagnosis of autism was proposed by Frano Petric [33]. This protocol is based on four tasks extracted from the Autism Diagnostic Observation Schedule (ADOS), and modified to be implemented using humanoid robots. By using this approach, the authors believe that diagnosis of ASD can be standardized, improving accuracy and consistency.

In terms of treatment, existing research has been focused in three main categories: the use of robots to (a) increase engagement and motivation; (b) elicit behaviors and (c) model, teach, and/or practice skills [34]. These outcomes vary according to the intervention method, the robot being used and the severity of the child's symptoms. For example, a nine-month trial conducted using an anthropomorphic robot, 'Lucy', aimed to enhance sensory enrichment and provide assistance through free interaction in a home-based care environment [35]. Other examples include: semi-structured interactions with the humanoid KASPAR, to increase body awareness in children with autism [14], and semi-structured play with the robot CHARLIE, to promote communication and social skills [15]. Although researchers have developed a wide range of robots, humanoid shapes with human-like behaviors seem to offer the most promise for ASD therapy and education [36, 37].

Research in SARs to support verbal communication in autistic children is limited. It has been shown that children with ASDs speak more during triadic interaction, while interacting with a robot than with another adult or a touch-screen computer game [38]. Similar results were observed by Srinivasan [39], who suggests that robot-child interactions can be used as a potential tool to encourage spontaneous verbalization in autistic children. Sakka et al. [37], furthermore, used a humanoid during a 20-week intervention program supported by speech therapists, and observed improvements in verbal communication that were motivated by the participants' desire to use the robot. Verbal communication started with questions about the programming, and eventually progressed up to the level of discussion.

This study extends this small body of research by introducing robots into the education system and reporting on observations made by teachers and parents of improvements in students' articulation and verbal participation.

IV. METHODOLOGY

The aim of this study was to collect insights from parents, carers and staff members about the long-term impact of the SARs at the disability unit (DU) from a public secondary school. Observations of the potential benefits, challenges, limitations and opportunities of this technology were explored. The study was implemented 24 months after the introduction of two humanoid robots at the DU. Over the 24-month period, 28 children were enrolled and had multiple opportunities to interact with the robots. During this time, the robots were used a number of times per week, depending on the teaching requirements and other demands across the DU. Students had no access to the robots during school holidays.

Ethics approval was sought and obtained in July 2017. All parents/carers and staff members who were involved with the students from their DU during the 24-months period were invited to participate. Nine focus groups and semi-structured interviews were conducted between July and November, 2017. These focus groups brought together six parents/carers, six teachers, and six additional staff members including the school Principal and school services officers (SSOs). Each focus group was audio recorded and a thematic analysis was undertaken by the researchers. Full details of the study and experimental results are presented elsewhere [17]; here we focus on the impact of the robots on the students' verbal communication skills.

A. Context of the disability unit

This study was carried out at the disability unit (DU) from a public secondary school located in the heart of the Murraylands in South Australia. It is a regional secondary school in a low socioeconomic area. Eligibility for enrollment is determined by an educational psychologist, and includes students with moderate to severe intellectual disabilities, language communication disabilities, autism, Down Syndrome and significant severe and multiple disabilities. It accommodates the learning needs of students aged between 13 and 19 years in two vertically grouped Middle School and Senior classes. Between 21 and 30 students are enrolled every year.

Students from the DU engage with a wide range of digital technologies to access the prescribed Australian curriculum, including laptops, iPads, Raspberry Pis, a 3D printer and Lego Mindstorms. Additionally, in 2015, two NAO robots were integrated into the DU to provide students with additional practical support to further develop their confidence, social skills and communication skills. It was expected that the robots would stimulate social interaction by providing appropriate emotional, cognitive and social support.

B. NAO at the disability unit

NAO is a small (58 cm height, 4.3 kg weight), autonomous, programmable humanoid robot developed by SoftBank Robotics (Fig. 1). It is controlled using a Linux-based operating system, and includes a graphical user interface (Choregraphe) that allows users to program it without the need to write code. The hardware platform includes: tactile sensors, speakers, microphones and video cameras, as well as prehensile hands with three fingers. It can reproduce sound, synthesize speech, and understand verbal utterances. NAO allows for a range of applications that stimulate the development of social and communication skills.

The DU integrated two NAO robots to reinforce learning across the curricula. The robots were individually scripted and programmed by staff members (using Choregraphe) to provide specific guidance and instructions during lessons, encourage students to express their ideas and provide positive feedback and reinforcement. Lessons were often reviewed, modified and repeated according to the students' needs and interests, teaching requirements and other demands across the learning areas.

Delivery of robot-assisted lessons were generally done with groups of five to ten students, where the robots acted as an instructor or a social mediator, and provided students with the opportunity to take individual turns. Lessons were structured following different formats including: performance, role-playing, step-by-step instructions, and questions and answers. Under the programmed instruction from NAO, for example, students designed pictures using shapes, cooked meals in a training kitchen and constructed Leonardo da Vinci's self-supporting bridge. Performance and role-playing, furthermore, were used to share information and model behaviors related to physical activities, personal safety (e.g. the use of a kitchen knife) and social interaction. Each individual session would run for approximately 30-45 min.

The robots were scripted to respond to the students' speech or touch according to the requirements of the lesson. The LEDs in their eyes were programmed to change color depending on the context of the script, or when the robots were ready to listen. Together, these behaviors encourage turn taking, eye contact, active listening, social interaction and social communication.

Members of staff were gradually introduced to the complexities of the new technology, which they may have otherwise found challenging and intimidating. Firstly, familiarization with the Choregraphe software was essential in order to program specific applications that achieve the desired learning outcomes for individuals or small groups of students. Consequently, students were exposed to progressions of experiential learning with multiple levels of engagement.

V. RESULTS

Overall, participants (parents, carers and staff members) responded positively toward the use of robots within the DU, and mentioned that NAO was particularly beneficial for students with at least a basic level of cognition and verbal abilities. Participant observations of the robots' potential to provide benefits in non-verbal communication skills, life skills and social skills are published in [17]. Here, we focus on the significant influence the robots had on the verbal

Fig. 1. The NAO robot interacting with a student at the DU.

communication skills of students. Three case studies were chosen as representative of skill acquisition. To protect the students' privacy, we will refer to them as Ross, Ben and Jack.

A. Case study 1 – I can speak clearly now: Ross' enunciation improves in order to instruct the robots

Ross is a male senior student at the DU. He was first assessed and given a provisional diagnosis of autism in 2003, at the age of four. At the time, he actively avoided making eye contact, his facial expressions and gestures were incongruent with his mood and behavior, and he was not able to interact with his peers in an age-appropriate, socially-reciprocal manner. Ross' development of spoken language was significantly delayed, and demonstrated stereotypical, repetitive and idiosyncratic language.

In 2011, Ross undertook a second psychological assessment, with most of his scores falling under the 1st percentile (similarities, vocabulary, comprehension, picture concepts, matrix reasoning, coding and symbol search). Perceptual reasoning and arithmetic averaged in the 2nd percentile, Block design in the 37th percentile and digit span in the 9th percentile. Ross' teacher also completed an ABAS II, confirming that while his scores were low, he performed better in all areas at school than at home. He was then diagnosed with an ID.

Ross has received speech therapy over the years, with particular focus on articulation and speech clarity. In 2008, the speech pathologist reported a possible mismatch between the neurological representation of the sounds, Ross' production of sounds and his auditory perception of his own speech. As a result, Ross does not like his speech corrected as he believes he is saying the sounds correctly. During his early secondary years, he continued to have a significant speech impairment, and made little attempt to use any of the long 'fricative' sounds at the beginning of words.

Ross joined the DU at the age of 13. Focus group participants noted that his transition into the senior class was challenging, as he was expected to work outside his comfort zone. He displayed high levels of anxiety and low confidence, particularly during one-on-one conversations. His speech was limited, mumbled and would speak at a very low volume.

> *[Ross'] biggest challenge he always found is, when you are asked a question and then you have to give the answer, he could never do that because he was afraid that he would be wrong.* [Parent 1]

According to participants, Ross was immediately attracted to the NAO robots. Since their introduction, he showed increased levels of confidence and participation. He understood that he needed to make a considerable effort to speak clearly to the robots, otherwise they would not respond to him. Motivated by his interaction with the robots, he would practice at home words that were needed to effectively interact with them. His commitment to speak louder and more clearly was evident, and his level of verbal communication steadily improved.

> *[Ross'] enunciation is slowly getting better, and he makes a concerted effort when he is using the robots to speak a lot more clearly and a lot louder.* [SSO 1]

> *[Ross] had to work a bit harder so that the robots could understand him... it helped with his language. He is now able to stand up and speak, whereas before he used to stand back and let everybody else talk for him.* [Parent 1]

Ross became more confident and now expresses his feelings. He developed some leadership skills, and enthusiastically and successfully participated in all aspects of the curricula in his last year of school. Ross' case highlights the robot's potential to facilitate skill acquisition in spoken language.

B. Case study 2 – From avoidance to empathy: Ben comes out of his shell

Ben was diagnosed with autism at the age of 2.5. In 2011, at the age of 13, he undertook the WISC-IV Full Scale IQ test and was found to be well below average regarding conceptual insight and abstract reasoning; ability to understand and express word meanings; measures of practical knowledge and social judgment; abstract conceptual reasoning ability; short term auditory memory and attention; sequential recall and mental arrangement; short term visual memory and coordination. He scored 'low average' in fluid conceptual reasoning and processing speed; and scored 'average' in abstract visual perception and reasoning. Ben also undertook the ABAS-II questionnaire, and obtained low scores in all the conceptual, social and practical domains. The scores indicated that he was low functioning overall, with the exception of visual spatial skills where he was low average. Ben joined the DU at the age of 13. He presented aggressively towards staff and students, and demonstrated similar behavior at home. He would not verbally communicate with staff or peers. He required high levels of support and prompting to remain on task, and recommence work after breaks. While Ben does not initiate verbal communication, he would respond to 'Good

morning'. He is self-talk and often loud and distracting to others. He doesn't like assistance or closeness.

> He has a lot of self-talk and it's movie related. He also doesn't like assistance. He doesn't like closeness. If you go near him, he'll push you away. [SSO 2]

When the NAO robots were introduced at the DU, in 2015, Ben showed little interest in interacting with them for approximately 6 months. In fact, during the initial weeks, he would put his hands over his ears and shout: "Stop! Stop!" when the NAO robots were speaking. One day, as he was walking past one of the robots standing on the teacher's desk, he stopped and began talking to it. He was then invited (by a staff member) to join the robot in a private room, where he happily responded to the robot's questions. Ben and the robot maintained a conversation for approximately 20 minutes; the robot's conversation was remotely controlled by a staff member. According to the DU manager, that was the first time they had ever heard Ben having any sort of conversation for longer than 30 seconds.

Since then, Ben continued to work with NAO and would readily give it instructions to activate the various apps. He took every opportunity to interact with the robots, and liked to communicate with them. According to participants, he would also show feelings and empathy towards the robots, similar to those he shows towards people.

> When the robot falls, he's the first one to say, "Oh my goodness are you alright?" [SSO 2]

Ben has left school and is now working in supported employment. Ben's case highlights the robots' potential to facilitate skill acquisition in spontaneous conversation.

C. Case study 3 – Through vicarious play: Gentle Jack joins the group

Jack is a male student with a history of cerebellar vermis hypoplasia, strabismus, serious otitis media and developmental delay. In 2002, at the age of 2.5, he undertook the Griffiths Mental Developmental Scales (GMDS) and his results indicated severe global developmental delay. At the age of 5 he was speaking in single words, had limited vocabulary, and had difficulty understanding verbal instructions. The WPPSI-III showed that Jack was functioning within the extremely low range of intellectual development, with an IQ of 45. In 2008, Jack undertook the Stanford-Binet Intelligence Scales and his results demonstrated significant delays in knowledge and working memory (age equivalent of 2 years); fluid reasoning (2 years 4 months); quantitative reasoning (2 years 8 months) and visual spatial processing (3 years 6 months). He was diagnosed with an ID.

In 2013, Jack presented at the DU as a shy Year 8 student, who was unwilling to communicate using words or phrases, preferring a range of guttural sounds and gesticulations. He required frequent prompting to remain on task. He was self-conscious, and displayed high levels of anxiety and low confidence.

> Because he has a speech impediment, and he was self-conscious... if you asked him a question, even if it was a yes/no, he would just sit there and make no response whatsoever. [SSO 3]

Jack enjoyed working with the NAO robots soon after their introduction at the DU. He would try to talk to them and listen to their instructions. He would use flash cards and tap their heads in order to interact with them. Even small changes in his confidence and verbal enunciation took months to develop, after interacting with the robot dozens of times. His main motivation, as highlighted by participants, was observing other students interacting with NAO. After the robots had been in the DU for over 12 months, Jack was able to answer questions, and actively engage and participate in group activities, with support from the SSO as required.

> ... with the reading, he'll read out loud to the group where he would never read before, he would just sit there. [SSO 3]

Jack's case highlights the robot's potential to facilitate skill acquisition in verbal participation.

VI. Conclusions

These three case studies demonstrate that teachers, carers and parents perceive robots to be facilitators in communication skill acquisition, particularly for articulation, spontaneous conversation and verbal participation. The three students became more confident and willing to engage in conversation after interacting with the robot over a period of time. All of the students enrolled in the DU took the opportunity to interact with the robots. For some students, progress was more marked than for others, and the acquired skills were relative to, and dependent on, the cognitive ability of the student.

Without doubt, the NAO robots have enriched the learning experiences of students. The robots have become rewarding social partners, facilitating intrinsic interest through various levels of social communication and interaction.

More work is needed to evaluate if the observed benefits can be replicated across different schools. Additionally, the current study presented an evaluation from the perspective of parents/carers and staff members. Future work should be considered to evaluate the effects of SARs using pre- and post- intervention measures of learning that can be quantitatively compared in similar situations with and without the use of SARs.

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