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Interlocutors and Interactions: Examining the Interactions Between Students With Complex Communication Needs, Teachers, and Eye-Gaze Technology

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Abstract

This study analyzes the role of the machine as a communicative partner for children with complex communication needs as they use eye-tracking technology to communicate. We ask: to what extent do eye-tracking devices serve as functional communications systems for children with complex communication needs? We followed 12 children with profound physical disabilities in a special education classroom over 3 months. An eye-tracking system was used to collect data from software that assisted the children in facial recognition, task identification, and vocabulary building. Results show that eye gaze served as a functional communication system for the majority of the children. We found voice affect to be a strong determinant of communicative success between students and both of their communicative partners: the teachers (humans) and the technologies (machines).

Keywords: human-machine communication, interpersonal communication, eye-gaze communication, communicative partner, communication disability, special education, educational technology

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Introduction

Advances in digital technologies provide opportunities for users to directly interact with software and devices, supporting human cognitive processes related to communication. This is potentially beneficial for users with cognitive deficits and/or physical disabilities. The case for human-machine communication is strong for people for whom the machine is not only a tool, but is an integral part of their expression and access to information. As examples, screen-readers have facilitated internet access for blind and vision-impaired users (Chandrashekar & Hockema, 2009); iPod touch and tablet devices have provided a means of expression for nonverbal children with autism (McEwen, 2014; Hourcade et al., 2012); location-based applications can support life-skills curriculum (e.g., attention, motivation) for students with developmental disabilities (Demmans Epp et al., 2015), and e-gaze glasses can support communicative interactions between blind and sighted people (Qui et al., 2016; Qui et al., 2018).

Yet even as technology designers continue to learn and find optimal approaches to meet the needs of a wide range of users, those with more complex disabilities remain hard to support as so much remains unknown about how learning occurs. Prior to the 1950s, people with communication deficits, particularly those classified as nonverbal, were not accommodated in formal education systems and were considered to be brain damaged and of lower intellect (Botting, 2004) best served by institutionalization. Pedagogical techniques were, and to some extent still are, based on oral and written skill delivery and demonstration. Without functional language, education was difficult and often abandoned for this population. For neuro-typical children, speech development occurs between the ages of 18 months to 3 years, and while it is a complex social process, speech development is part of the anticipated developmental stage of early childhood, with significant delays signaling potential physiological and/or neurological concerns (Sladen, 1974). Depending on the individual's capabilities, when speech is delayed, underdeveloped, or absent, other communication systems are called upon as substitutes, such as sign language or picture exchange communication. However, when physical disabilities are also factors, such as an inability to use the hands or control facial expressions, the ability to communicate is considerably more difficult. It is only within the past 80 years that cognitive science research on nonverbal communication provided indications that there are other mechanisms available for expressive and receptive communication for those with complex communication needs.

Eye-tracking devices with voice output have recently emerged as potentially useful assistive communication technologies for those who are nonverbal and unable to use their hands for command input. Despite a need for more research on alternate and technology-centered communication systems, there are few studies (Gilroy et al., 2017) about elementary school-aged children who have complex communication needs. This is due to several factors: the smaller number of research participants within public elementary school settings; more onerous human ethics protocols for researching this population; and the challenging nature of designing research of nonverbal and communicatively challenged children, where traditional research methodologies like interviews and observation are not easily implementable. Therefore, it requires an approach to data collection that involves a careful development of measures in environments familiar to the students.

When at school, children with complex communication needs have additional adult support in their classrooms in the form of teachers and educational assistants. These adults work closely with their students and become important communicative partners, especially in the situation where the adult to child classroom ratios are small. When communication technologies are present in this type of scenario, the classroom environment includes technical and non-technical elements that, in combination, present a fertile ground for research on communication. Literature on disabilities note that restrictions in participation in the venues available to others is the everyday experience of persons with disabilities and that communication media can play a part in reducing the barriers to participation (Ellis & Goggin, 2015). Studies in school settings show that educational technologies are being incorporated into the classroom with the goal to improve learning outcomes, particularly for learners with needs requiring alternate approaches (Demmans Epp et al., 2015; Edyburn, 2013; Goggin & Newell, 2005; McEwen, 2014). However, while a focus on educational technology can support better technology design and curriculum integration, studying the role that the technology itself plays in interaction is an understudied aspect and relevant to studies of human-machine communication. The latter is the focus of this paper, and the school setting does not suggest a focus on education, but is strategic as it provides access to an understudied population that aggregates in few other spaces.

Theoretical Framework

To frame this as a communication interaction study, we turn from the educational technology literature to draw from theories in Science and Technology Studies (STS) and Human-Machine Communication. Twentieth-century, Western-scientific traditions adopted a non-technical versus technical dichotomy as a foundational premise in academia (Grint & Woolgar, 1997; Suchman, 2008), and in so doing drew a boundary between the technical and the social-psychological. On one side of this binary are technological artifacts and, on the other, social entities—in other words machines versus humans. The epistemologies that supported this construct included technological determinism on one side and humanist perspectives on the other. Each theoretical approach struggles to reposition either technology or people in the center of the analysis. Personal digital media that are deeply embedded in daily communication have called this conceptual separation into question. In the works of Vygotsky (1978) and later Latour and Woolgar (1979), STS scholars consider meaning-making as occurring within a particular social context. For scholars of this tradition the social context, which includes all of the elements in the communicative environment, is the focus from which technological and human interactions may be understood. The familiarity from everyday use of digital devices obscures their role in communication to human participants and observers. A key aspect of the theoretical framing of this study is the notion that when we use a digital technology for communication, we are also engaged in communication with the device itself.

Extending Niklas Luhmann's (1992) definition of communication that considers the bidirectional understanding that must occur for successful communication, we consider the elements of human-machine communication that occur when we engage in mediated communication. These elements include the affordances of the technologies, and the abilities of the users (Dubé & McEwen, 2016). Along with scholars who similarly posit that sociotechnical interactions are co-constituted, Wanda Orlikowski (2007) believes that neither humans nor technologies should be privileged in research analyses. Following from works of Suchman (2008) and Barad (2007), Orlikowski (2007) claims that in constitutional entanglement, ". . . the social and the material are considered to be inextricably related—there is no social that is not also material, and no material that is not also social" (p. 1437). Likewise, for human-machine communication scholars the distinction of humans and technologies is purely an abstraction since these entities relationally enact each other in everyday practice (Guzman, 2018). Drawing from this co-constitutive and human-machine communication theoretical frame, we designed our study of the interpersonal communication between teachers and students to also take into account the eye-tracking technology itself. The technology is not considered as simply a mediating device, but an active participant in the communication taking place.

Background

For the purposes of our study, we define the three communication units involved as illustrated below: (1) Individuals with complex communication disabilities, (2) the human communicative partner, including teachers, educational assistants, and therapists, and (3) the machine or assistive technology that enables the communication and supports the interactions for individuals with complex communication disabilities.

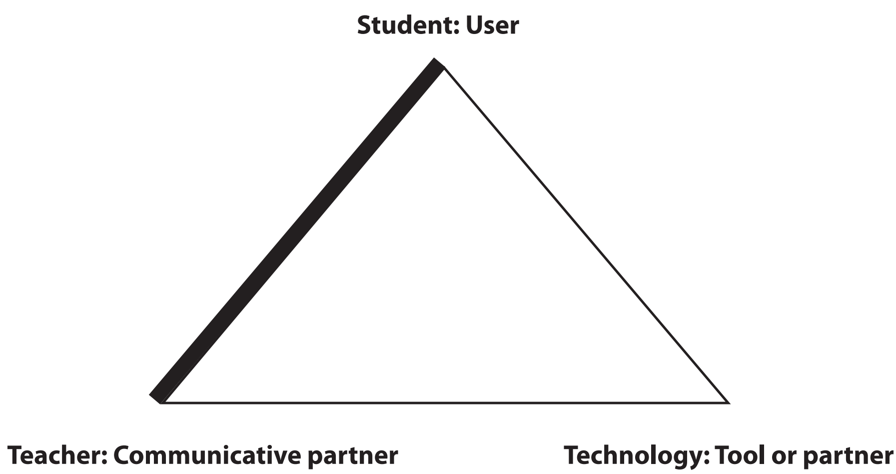

FIGURE 1 Communication Units

I. Student: Users With Complex Communication Disabilities

The first unit of analysis is the user and, in this case, students with complex communication disabilities. Children with multiple disabilities such as language, motor, and other impairments do not develop speech skills as expected and have limited opportunities for communication (Light, 1997). We follow 12 students with complex communication disabilities who use augmented and alternative communication (AAC); that is, communication techniques used to supplement or substitute spoken or written communication for those with impairments. Four out of the 12 students are officially diagnosed with Rett Syndrome (RS), and others with cerebral palsy, chromosome deletion, seizure disorder.

Eye gaze was reported as the most commonly used modality for expressive communication for individuals with RS (Bartolotta et al., 2011; Urbanowicz et al., 2014), which raises the opportunity to explore eye-tracking technology as a means to enable communication and improve communicative capabilities for individuals with RS. In a study of nonverbal cues, eye gaze was identified as a key feature in following conversational sources including in mediated exchanges (Vertegaal, 1999) and in an analysis of conversational attention in multiparty conversations, eye gaze was found to be an excellent predictor of conversational attention (Vertegaal et al., 2001). Another study explored the application of eye-tracking technology to analyze the intentionality of gaze of seven girls diagnosed with RS. Results show that eye gaze was intentionally used to perform three cognitive tasks with high accuracy, suggesting that eye gaze could be used for communication by people with similar limitations (Baptista et al., 2006).

Based on the existing literature, and given a gap in the literature since more recent evolution of eye-tracking technologies, our first research question (RQ1) asks: To what extent do eye-tracking devices serve as functional assistive communication systems for students with complex communication needs?

II. Teacher: The Communicative Partner (Human)

The second unit of analysis is the person/human with whom the student is communicating with; in this case, the teacher or educational assistant. For the purposes of simplicity, we will use the term teacher throughout this article to describe the adult educator working with the student. Mackenzie and Stoljar (2000) point out that "persons are socially embedded and that agents' identities are formed within the context of social relationships and shaped by a complex of intersecting social determinants . . ." (p. 4). Within school environments teachers can be considered to be important agents whose identities are partially shaped by interaction with each other and in day-to-day encounters with their students (Fredricks et al., 2004).

Communicative Partner's Language Style

Conclusions from prior research indicate that girls with RS learned to communicate more frequently and intentionally as a result of storybook reading with their mother (Skotko et al., 2004). The mothers were trained to attribute meaning to the girls' attempts to communicate, ask communicative questions, and prompt the use of communication devices or symbols through natural questions and comments rather than commands. This style of communication is more naturalistic and the use of an inflected tone, one with excitement and higher than usual emotional content, is more engaging. When parents used this inflected voice approach during storytelling it resulted in an increased number of communication attempts and communication means.

However, this approach is not standardized and is sometimes actively discouraged in the developmental communication literature. In studies of children with cognitive impairments researchers found that neutral voice affect mitigated difficulty that some children have with identifying the appropriate prosody or emotion of the speaker's words (Hobson et al., 1989; Stewart et al., 2013). Another study linked a specific region in the brain as the site where processing of prosody appears to be negatively impacted for people with neurological impairment, with recommendations for the use of neutral and uninflected tones to reduce the cognitive load (Wang et al., 2007).

Guided by this debate in the literature our second research question (RQ2) asks: What role does the communicative partner's language style (voice affect inflected vs. neutral) play in communicative outcomes when using eye-gaze technology?

Communicative Partner Familiarity

In a survey distributed to 141 parents, teachers, and health care professionals, the majority of respondents believed that people familiar to individuals with communication disabilities can better interpret their communication than unfamiliar people (Bartolotta et al., 2011). While familiarity offers more comfort in a social environment, in special education where there is greater likelihood that a nonverbal student's needs require some assistance and interpretation, there is a risk for the student to lose degrees of agency and self-determination. Facilitated communication, a method in which people who lack functional speech, usually due to a developmental disability, input commands into a device with the assistance of a facilitator (Stock, 2011; Wheeler et al., 1993), is a controversial issue. At the heart of the debate is the potential loss of independence and agency for the person being assisted—is their voice being heard or is it being directed by facilitators who are familiar with the person communicating? In addition, there are instances where the communicative partner may encounter challenges interpreting and identifying communication intentionality.

Identifying the intentionality of communication in individuals with autism or other communication disabilities is often exacting (Iacono et al., 1998) and communicative partners can exhibit inconsistencies in identifying behaviors that serve as a mean of communication (Mattews-Somerville & Cress, 2005). In addition, familiar partners are not always available necessitating communication systems that can be generalized to persons who may not know the individual trying to communicate.

Based on this, our third and final research question (RQ3) asks: What role does the familiarity (or unfamiliarity) of the communicative partners play in communicative outcomes when using eye-gaze technology?

III. Eye-Gaze Technologies

According to Goossens and Crain (1987), numerous eye-gaze communication techniques have appeared in literature since Eichler, McNaughton and Kates, and Vanderheiden (p. 77). The introduction of electronic eye-tracking systems allows the computer to handle almost the entire process of decoding the gaze for the purpose of message selection and confirmation. Because the eye-tracking software also acts as a speech-generating device (SGD), the child can initiate a conversation by gazing at an object on the screen, prompting computer-generated speech. The partner can focus on responding to the message that the child is communicating without having to also verbalize what they see the child is looking at (Gillespie-Smith & Fletcher-Watson, 2014). The child no longer needs to look at the human communicative partner to initiate a message or rely on them to determine the path of their visual attention. Gaze toward the human communicative partner becomes more socially weighted, such as communicating a sense of interest in the person themselves or to express excitement in the conversation (Djukic & McDermott, 2012). Another consequence of using technology for users with complex communication needs to increase their levels of *agency* which can be defined as "being in a state of action or exercising power, or as being free to choose and act in a manner independent of the structures that limit or influence the opportunities that individuals have" (García Carrasco et al., 2015, p. 162). Given the one-on-one interaction between the participant and the eye-gaze technology, research question 1 focuses on the participant-device interaction.

Method

The data were collected in 2016–2017 in a special needs school in downtown Toronto, Canada. The Tobii-Dynavox eye-tracker system was used to collect data from software designed to assist the children in facial recognition, scanning, targeting, and task identification. Our data collection used The Tobii-Dynavox eye-tracker system which had two configurations: (a) an embedded system, the Tobii I-12 that came from the manufacturer on a stand which could be adjusted for height and angle and had a camera built into the screen; and (b) an improvised hardware system, which included a myGaze camera, Tobii-Dynavox software, and a laptop mounted to a portable stand.

FIGURE 2 Embedded System, Participant and Communicative Partner Example

The 12 participants used an educational software designed to improve proficiency in communication using images with associated labels or phrases. For example, a photo or line drawing of a dog would have the label "dog" typed below it and a pre-recorded, audible output of the word "dog" from the device if that image is selected by the user using eye gaze. Similarly, in a graphic image with many objects, eye gaze detected by the device on the image would result in the auditory output of the label or phrase pre-recorded for the object. Data were collected in familiar surroundings during scheduled instructional times in three classrooms and during regular school hours.

Participants

Participants were nonverbal students with a range of cognitive or developmental disabilities *(see Table 1), were aged 4 to 12, and met the following inclusion criteria: (1) had difficulty using their hands (i.e., they could not easily input commands into a device), (2) had limited speech and had little to no spoken language ability, (3) were sighted (i.e., have functional vision, where prescription glasses were allowed).

TABLE 1 Participant characteristics and diagnosis (n = 12)

Participant Code	Classroom ID	Gender	Age	Diagnosis
C04	112	F	4	Rett syndrome
L05	112	F	5	Rett syndrome
T06	112	M	6	Complex, not otherwise specified
Z07	112	F	7	Rett syndrome
A08	113	F	8	Complex, not otherwise specified
K05	113	F	5	Rett syndrome
N05	113	F	5	Cerebral palsy
R07	113	M	7	Chromosome deletion q13
R08	113	F	8	Brain injury
A11	116	F	11	Cerebral palsy
E09	116	F	9	Brain injury
L12	116	F	12	Seizure disorder

Prior to this study students had access to both low- and high-tech AAC devices in the classroom. Most participants (n = 11) had experience with some modes of analog and digital eye-gaze tracking communication. In the analog systems, students engaged in the selection of pictures with the aid of a communicative partner. For example, the communicative partner would hold two objects in front of the child and the child would direct their gaze toward their choice. The students also had some practice in establishing joint attention.

Procedure

The participants' social and communication skills were baselined using the Communication Matrix—an online communication assessment created for emergent communicators and those who use alternative communication systems (Rowland, 2011, https://www.communicationmatrix.org/). The Communication Matrix is a detailed assessment tool with categories defined for the skill identification of pre-verbal communicators and has been successfully used by the research team in previous studies (McEwen, 2014). Pre- and post-assessments were completed to track changes in communication development over the course of the project. This form of assessment is useful when chronological or developmental age normative classification are ambiguous and/or misleading. When studying children with disabilities using intergroup profiles of normative skill acquisition is not applicable since the chronological ages and developmental ages do not often match (Rutter, 1989; Tsao &

Kindelberger, 2009). Instead, we consider inter-individual variability in their cognitive functioning by using tools like the Communication Matrix in pre-post design.

Before the research project started ethics clearance was received from the Toronto District School Board and from the University of Toronto, including written parental consent as part of the protocol. Data were collected using video and screenshots that were loaded onto an assessment tool for educators (SesameSnap) and stored in a password protected online format. Data were also collected in the Communication Matrix software where the system assigned them a random ID, which the research team appended with the assigned anonymized ID codes as previously described.

Analytical Measures

Four measures were selected to investigate the research questions. RQ1 is concerned with the extent to which eye-tracking devices can be used for functional assistive communication. *Session time* is defined as the total amount of time that the student participant and device are engaged in a communicative interaction, measured in minutes and seconds. Several previous studies (DeVito & DeVito, 2007; Duck et al., 1988; Emmers-Sommer, 2004; Luhmann, 1992) found that prolonged communication is a significant predictor of successful interactions. Therefore, longer session times would indicate interest, motivation, and overall effectiveness in communication, especially between the device and the participant. RQ2 asks what role the communicative partner's language style or voice affect plays in communicative outcomes when using eye-gaze technology. As discussed in the earlier background section, previous research findings are contradictory regarding neutral versus inflected tones of voice used by the communicative partner, thus we examine interactions with *inflected* and *neutral* tones of voice. We trained communicative partners in the use of high and low affect voice, using voice samples to maintain consistency. Finally, RQ3 considers how *familiarity* between the communicative partner and the participant affects communicative outcomes, thus whether or not the communicative partner is familiar to the student is the final variable under investigation. This is measured in the amount of contact time that the communicative partner had with the participants prior to the study, with minimal contact (less than 1 hour per week), average contact (between 1 and 3 hours per week), and high contact (over 3 hours per week) as the classification points.

Data Collection

Data collection was conducted by the three classroom teachers over a 3-month period. Teachers videotaped the students while they used the eye-tracking devices. Data collection sessions occurred twice a week. Participants were tasked with using software with phrases and labels to identify objects. One application is called Sono Primo software (Tobii Dynavox Ltd.) which includes eye-tracking software for developing AAC skills. Learners look around interactive scenes (e.g., farm, birthday party) and the visual targets play related sounds, including phrases and labels, when triggered. Familiar partners were the students' regular teachers, who spent time with them during regular classroom instruction. Unfamiliar partners were other teachers or assistants who worked elsewhere in the school. Unfamiliar partners were familiar with the instructional environment and have experience working with children with disabilities and developmental delays, but did not know the students personally. Both partner types used a mix of inflected and neutral tones in different sessions, to allow for researchers to analyze the impact of both variables against the different partner types.

Coding and Analysis

All of the video data were coded independently by three final-year undergraduate students supervised by the principal researcher. Three undergraduate researchers from the team started by selecting a sample of videos from the three classrooms for comparative assessment as a group to synchronize the coding for inter-rater reliability. They made qualitative notes on the videos, looking for variables that could be used to assess the validity of the hypotheses that followed from the research questions. A codebook was developed to guide the rest of the coding process. The team met twice for calibration and inter-coder reliability checks. The data were analyzed using IBM SPSS software, using a paired-samples t-test for comparing pre- and post-intervention Communication Matrix assessments.

Linear Generalized Estimating Equations (GEE) analyses, which is appropriate for the analysis of data collected in repeated measures designs (Ballinger, 2004), were used to determine whether the duration of eye-gaze sessions is predicted by voice affect and partner type. Seven videos from four of the participants (K05, C04, A08, and E09) were transcribed to explore the quality of interactions within the sessions. Using a multimodal interaction methodological framework (Norris, 2004), the transcriptions include descriptions of the surrounding environment, the position of the participants and their partners, nonverbal utterances and facial expressions, and body movements. Multimodal analysis describes the use of data from gestures and movement in communication—this is an important consideration in all communication but more so in communication on nonverbal people.

Results

Communication Matrix assessments: RQ1 questions the extent to which the eye-gaze system in use served as a functional assistive communication device for students with complex communication needs. Eleven of 12 students completed both pre- and post-intervention Communication Matrix assessments. Figure 3 below presents comparative pre- and post-intervention Communication Matrix scores, which shows that 8 of 11 students who used the eye-gaze technology showed improvement in their communication skills, while one showed no change. According to a paired samples t-test, we found a significant difference in the scores for the pre-test ($M = 41.00$, $SD = 23.99$) and post-test ($M = 52.91$, $SD = 34.90$), $t(10) = 3.01$, $p < .05$.

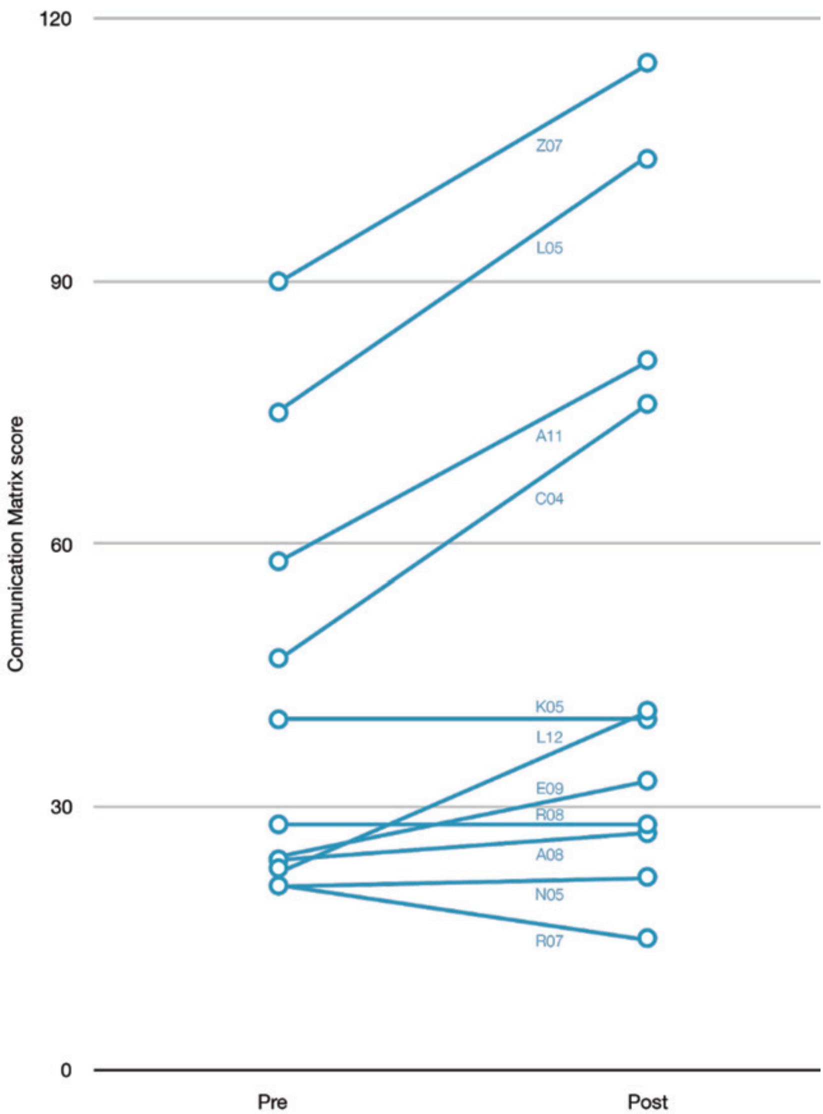

FIGURE 3 Pre- and Post-Intervention Communication Matrix Scores (n = 11)

Session Time

Regarding RQ1, capturing variable session length produced valuable results. A total of 164 testing sessions were conducted with an average number of 9.25 sessions per student (SD = 7.35; range = 2–24), lasting an average of 154.54 seconds (SD = 32.20). Teachers confirmed that these interactions were longer than is typical, where on average non-eye gaze mediated interactions are between 35–50 seconds. When cross-tabulating session time with the variable of voice affect from the second research question (RQ2), we found that voice affect significantly influenced the length of interactions (summarized in Table 2).

Table 2 Descriptive Statistics for Session Time Data (seconds)

	Number of Sessions	Mean Session Time (seconds)	Standard Deviation
All sessions	164	154.54	32.20
Communicative Partner Type			
Familiar	60	134.47	106.61
Unfamiliar	29	111.76	87.92
Voice Affect*			
Inflected	59	148.61	105.25
Neutral	25	92.96	44.87

Table 3 Mean Session Time (seconds)
Data Organized by Communicative Partner and Voice Affect Variables

	Communicative Partner Type								
Voice Affect	Familiar			Unfamiliar			Both		
	M	SD	n	M	SD	N	M	SD	n
Inflected	150.28	95.58	43	144.13	131.25	16	148.61	105.25	59
Neutral	95.94	47.51	16	87.67	41.94	9	92.96	44.87	25
Both	134.47	87.92	59	111.76	106.61	25	n/a		

General Estimating Equations were used to evaluate the effect of voice affect on session time, which found that sessions with infected tone were predicted to be significantly longer than sessions when communication partners used a neutral voice ($p < .001$). When cross-tabulating session time with the variable of familiarity of the communicative partner from RQ3, we found that sessions conducted by a familiar communicative partner were not significantly longer ($M = 134.47$; $SD = 106.61$) than those conducted by an unfamiliar communicative partner ($M = 111.76$; $SD = 87.92$), as determined by the GEE approach ($p = .307$).

Further analysis (summarized in Table 3) indicates that sessions with a familiar communicative partner using an inflected tone were associated with the longest sessions ($M = 150.28$, $SD = 95.58$), followed by sessions with an unfamiliar partner using an inflected voice ($M = 144.13$, $SD = 131.25$). Sessions in which communicative partners used a neutral tone were shorter, with familiar partners sessions being slightly longer ($M = 95.94$, $SD = 47.51$) than unfamiliar partners on average ($M = 87.67$, $SD = 41.94$).

Multimodal Analysis

Results of the Multimodal Analysis also respond to RQ1. At seven minutes and eleven seconds into the session the following example comes from one of the longest interactions with a child and a familiar partner.

Teacher: What else is up here? [short pause]

Eye-gaze system: Can you help me?

Teacher: Help you do what? We just did brush your teeth. What else should we do?

[Camera pans back toward C04, C04 was looking at the teacher but turns head slightly back toward system]

Eye-gaze system: [*cursor lights up around the picture of a faucet*] I need water.

Teacher: (pretends to gasp) Oh. We can get your actual drink if you want a drink. Yeah, I'm happy to get you a drink.

In this example teacher is very expressive and uses a highly inflected voice throughout the interaction. The recording starts with the teacher repeating a request made by the child for water and pretending to pour some for the student. The child responds with a verbalization and the partner prompts her to try a different request. We hear the software in the background say, "Can you help me?" This lights up a stick figure with a toothbrush and the teacher offers to help the child with brushing her teeth. She mimes it with animated sounds, making the child smile. We see that the child will repeat the request for water through the eye-tracking system and the teacher will suggest getting a real drink in case she is thirsty.

We note that the immediate responses by the teacher to the communication by the student reduces the time between prompt and response. There were several instances with other participants where this became evident, possibly associating voice affect with reduced time between prompts and response with evidence of prompts fading over time; however, this requires further investigation.

Discussion

From the results we can annotate the initially proposed model of eye-gaze communication (see Figure 4). To answer RQ1, the data show that eye-gaze communication was a functional assistive communication system for the majority of the students with complex communication needs. Results show that students with complex communication needs are able to engage in richer exchanges with the device and teachers.

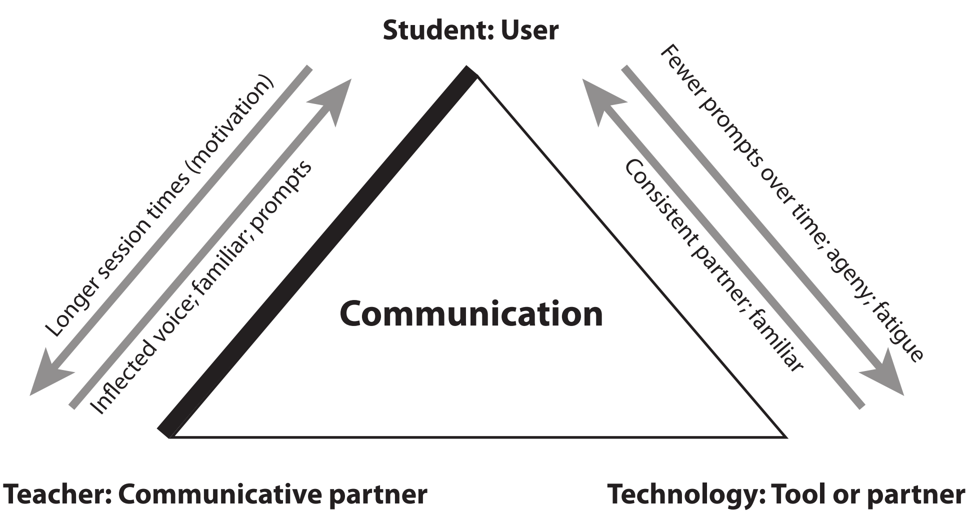

Figure 4 Modified Model of Eye-Gaze Communication

Communication Matrix data showed communication skill gains for eight out of 11 students; with one student staying the same. It is not clear why two students showed skill reductions, but since they were small changes it is possible that this indicates an error in measurement.

Regarding RQ2, we found voice affect to be a strong determinant of the interactions between students, their communicative partner, and the technology. While there is debate in the literature on whether or not neutral or inflected voice styles are recommended, the data in this research show that inflected responses by communicative partners were significantly correlated with longer engagements. When teachers used more inflected tones, students were also more expressive, visibly enthusiastic, and neither seem to be confused nor frustrated with the additional information within the exchanges. This suggests that with respect to eye-gaze technology use by students with diverse and complex communication needs, the communication style of the teacher plays a key role in positive outcomes.

The final research question, RQ3, focused on the role that the familiarity of the teacher played in communication. Results show that although sessions were, on average, slightly longer with familiar communicative partners than with unfamiliar partners, the difference was not significant. This is a somewhat surprising result as we expected a greater qualitative difference between sessions with familiar partners and unfamiliar partners, based on prior literature on familiar caregivers' role in interpreting communicative acts of children with communication disabilities (e.g., Sigafoos et al., 2011). Yet, our findings support prior studies that examined familiar and unfamiliar adults' interpretations of "potential" communicative acts in learners with RS (Julien et al., 2015) and found that the majority of familiar and unfamiliar adults were able to recognize potential communicative behaviors. This is an important finding because it suggests that among teachers in special education it matters less that students know them personally than it does the way that they engage with students. While we do not suggest that the quality of interactions between familiar and unfamiliar partners are comparable, we note that any issues encountered with unfamiliar partners were not problematic enough to cause breakdown of communication. One possible explanation is that although unfamiliar communicative partners were unfamiliar to the learners, they were familiar with the school and were well trained to address the communicative needs of the students in general.

Throughout the research project students demonstrated increased joint attention and reciprocal communication through eye-gaze with an expressive communicative partner through longer session times. In a form of cause and effect, students learned that they could make the system respond to their eye-gaze in a consistent manner that became familiar to them over time. For some students who have very little control over their bodies and, indeed, many aspects of their lives they could control a technology. The video data clearly showed an increase in agency by the students and an empowerment that likely contributed to their motivation to communicate, even when fatigue was also an outcome. It is possible that teachers would need to be mindful of students becoming overly reliant on the eye-gaze technology in the future; however, this study indicates that eye-gaze technologies have a role to play in the repertoire of assistive communication devices for children with severe deficits.

Applying a triad analysis to this research allowed us to pay more attention to the role that the technology played in the communicative exchanges. The eye-gaze technology was not simply a tool but was also a communicative partner to the student. The student was engaged in an exchange with the technology that required both sides of that dyad to have an accurate understanding of what was necessary for success. The students learned that by looking at the screen and holding their gaze, a voice output resulted that highly engaged their teachers.

When the technology worked according to plan, its affordances of consistency and reliability made it a familiar communicative partner and offloaded some of the effort on the part of the teacher in the exchanges. The technology as an active communicative partner appears to have changed the dynamic between the student and teacher, in some cases mitigating losses due to unfamiliarity between student and teacher. The technology became the consistent factor in the communicative system. For the student there were two communicative partners. This may be a factor in the level of fatigue that they displayed at the end of the sessions. Further study is needed to understand this outcome.

Conclusion

This research and its findings contribute to a small but growing literature on communication for people with complex needs. However, there were a number of limitations within the project that should be noted. There is some inconsistency in the number of sessions conducted within each set of variables. The staff's ability to collect data was subject to resource availability and was scheduled to minimize impact on classroom routines. There are more sessions with familiar partners, for instance, because they were the homeroom teachers and consequently available more often.

This is a preliminary study, and the sample size is small, albeit typical of a school setting that supports learners with this cluster of rare disorders. That said, we believe our findings may be more generalizable to other educational settings and reflect more genuine communicative contexts than other studies conducted in lab conditions with participants from the more general population. The results would benefit from replicated studies of RS learners using eye-tracking devices in other educational settings.

Interaction with complex, naturalistic scenes can be considered a form of gameplay, which is a high-energy interaction and demands quite a lot from the participants, particularly when the communicative partner uses an inflected voice. The resulting peak in communication skills could be short-lived, and children may return to normal modes of communication in day-to-day activities, with significantly less engagement through the communicative partner's voice affect in other contexts. It encourages them to play and to interact while in game mode, but may not be suitable in all interactions. That said, teachers did notice significant improvements in communication outcomes six months after the testing was concluded. In future studies, it may be helpful to substantiate this by completing a communication matrix for the participants 6 months out from the initial testing period. As technologies such as eye-tracking devices emerge it is important to identify the factors that affect outcomes. Studies that attend to young learners with more severe communication deficits can lead to implementable solutions at the school level with immediate positive impacts. The criticality of the role of the communicative partner is repurposed with the assistance of eye-gaze technology. The technology becomes an active agent, more than a passive tool, for the teachers to enable deeper engagement with students with complex communication needs.

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