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Voices from Academia

Eye-Gaze Access and Cortical Visual Impairment: A Case Study

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ABSTRACT

A feasibility case study was conducted to determine if eye-gaze training programs could be used to teach an individual with cortical visual impairment and cerebral palsy the visual skills necessary to operate an augmentative and alternative communication device using eye-gaze access. The individual was taught visual skills during phase 1 of the intervention through eye-gaze training programs, and communication was taught during phase 2. The individual acquired the necessary visual skills to operate the AAC device and demonstrated functional communication using the device.

***Keywords*: eye gaze, cortical visual impairment, intervention**

INTRODUCTION

Augmentative and alternative communication (AAC) can provide the necessary means of communication to individuals with complex communication needs. However, if an individual has multiple disabilities that affect their motor skills, hearing, and/or vision, it can be difficult to find an AAC system that best fits their needs. In addition to determining the best device, display type, and vocabulary set for the individual, the most reliable access method must be determined. Individuals with impacted motor skills who cannot direct-select through touch often require either an adaptive switch or eye-gaze access for their devices. An individual with a severe visual impairment may use auditory scanning with an adaptive switch to access their device. Adaptive switches come in a variety of forms but do require reliable motor control over one or more parts of the body in order to activate it. For an individual without reliable motor control, direct access through eye gaze may be the only feasible access option.

Eye-gaze access has advanced greatly and can now be used with a variety of individuals who require it. Most eye-gaze AAC systems contain an infrared light source that reflects off the eye of the user. The built-in camera then detects the reflection and calculates where the eye is looking on the screen (Mohamed et al., 2007). These calculations are made after calibrating the system to the user's eyes. To calibrate the system, the individual must fixate on specific points on the screen until calibration is successful. In order to use eye-gaze access for AAC the user must have the visual control to both scan the screen for the desired word and intentionally fixate on the word for a set time to select it. Therefore, eye-gaze access functions best when an individual has intact visual skills so they can view the screen and make selections through controlled visual behaviors.

CVI

Not all individuals who require eye-gaze access for AAC have intact visual abilities. One visual impairment that can co-occur with neurologic-based motor impairments is cortical visual impairment (CVI). CVI is a type of visual impairment of neurological origin resulting from bilateral dysfunction of the visual cortex and/or the optic radiations often caused by perinatal brain damage or trauma (Matsuba & Jan, 2006). Recent neuroimaging studies have demonstrated that many key neural pathways of the visual system may be affected in individuals with CVI (Martin et al., 2016). CVI affects 30–40% of the population that is visually impaired and is the leading cause of visual impairment in children in developed countries (Huo et al., 1999; Matsuba & Jan, 2006; Roman et al., 2010). In a review of infants 0–24 months with severe visual impairment with varying origins, CVI was the most frequent diagnosis, with 24% of infants in the study affected (Ozen Tunay et al., 2020). Individuals with CVI also tend to have concomitant disorders with reports of up to 90% (Ozen Tunay et al., 2020). One chart review study found that 75% of patients with CVI had at least one associated neurological deficit, with the most common being seizures (53%) and cerebral palsy (CP; 26%; Huo et al., 1999). Co-occurring ophthalmological deficits were also commonly found, including ocular motor deficits and refractive errors (Huo et al., 1999). It is unknown how many individuals who require AAC have CVI. However, with the majority of individuals with CVI having additional neurological deficits, there is likely overlap.

The visual deficits in individuals with CVI differ greatly from individuals with visual impairments due to refractive deficits. Although the presentation of CVI varies, there are common visual characteristics seen in this disorder, including oculomotor abnormalities, abnormal visual behavioral characteristics, and visual field deficits. A number of oculomotor abnormalities, varying in prevalence, have been found in patients with CVI, including limited fixations, deficits in smooth pursuit (tracking of an object), delayed fixations, impairment in ocular motility, strabismus, and nystagmus (Chang & Borchert, 2020; Fazzi et al., 2007). Additionally, abnormal visual behaviors are commonly observed in individuals with CVI that do not occur in other visual impairments (Chang & Borchert, 2020; Good et al. 2001; Jan et al., 1987; Jan et al., 1993). Individuals with CVI have impaired visual attention (Groenveld et al.,1990; Whiting et al., 1985) and attention tends to be better when viewing objects in motion than with static objects (Jan & Groenveld, 1993; Merabet et al., 2017). Individuals with CVI tend to supplement visual information with touch; however, they often look away from their target when reaching (Good et al., 1994). They often view objects closely, which may be a coping skill for the crowding effect they experience. The crowding effect occurs when multiple objects or pictures are displayed at once and the individual is unable to process the individual images (Groenveld et al., 1990). An attraction to colored objects has been documented (Baker-Nobles & Rutherford, 1995) as well as decreased contrast sensitivity (Fazzi et al., 2007). A sensitivity to light is common in CVI, with some individuals gazing at lights (Jan et al., 1990) and others experiencing photophobia (Jan et al., 1993). Lastly, individuals with CVI may experience visual field deficits that are often in the lower hemifield (Good et al., 2001; Kozeis, 2010).

There are a limited number of intervention studies conducted with children with low levels of vision, including children with CVI, and those that do exist have low levels of evidence (Chang & Borchert, 2020; Chavda et al., 2014). Improvements in visual skills have been observed in patients with CVI, but are often associated with age of diagnosis (Matsuba & Jan, 2006) and area of injury (Hoyt, 2003). Most often, improvements are seen when the child is diagnosed prior to age 3. This is thought to be the result of the plasticity in the young brain that can form new compensatory visual pathways (Huo et al., 1999; Lambert et al., 1987; Martin et al., 2016). However, many of the existing studies report improvements in visual acuity and few studies report changes in functional vision (Chang & Borchert, 2020).

Interventions for individuals with CVI include visual stimulation and modification of environment and stimuli to capitalize on visual strengths and compensate for specific deficits (Groenveld et al., 1990; Waddington & Hodgson, 2017). Visual stimulation typically involves exposing the child to a high-contrast image or light source to stimulate their visual system (Alimović et al., 2014; Alimovic et al., 2013; Tsai et al., 2016; Waddington & Hodgson, 2017). The programs usually consist of many successive trials. The stimuli used and length of trial is often individualized to the child’s strengths and deficits (Alimović et al., 2014; Tsai et al., 2016). Depending on the visual stimulation used, improvements can be made in visual acuity (Tsai et al., 2016), functional vision, and visual behaviors (Alimović et al., 2014). Greater improvements in visual functioning are seen when visual stimulation begins in the first 8 months of life compared to a start of treatment at 8–30 months of age (Alimovic et al., 2013). It is also unclear as to how long these improvements are maintained without continual use of the visual stimulation program (Waddington & Hodgson, 2017).

The literature has given suggestions on modifications to the environment and stimuli for individuals with

CVI as compensatory strategies with the goal of maximizing the use of the individual's functional residual vision (Good et al., 2001; Groenveld et al., 1990). Simplifying the visual environment focuses the individual's visual attention and reduces overload of the visual system (Groenveld et al., 1990). Visual information can be reinforced with tactile and verbal information, and rituals help to maintain consistency in the environment. When presenting stimuli to individuals with CVI, bright colors with high contrast and motion should be incorporated to utilize the strengths of detecting color and motion (Good et al., 2001).

Eye tracking is a new, innovative measurement vehicle to analyze visual behaviors in CVI (Kooiker et al., 2016; Pel et al., 2010). During these eye-tracking tasks, several visual behaviors can be measured through the presentation of different stimuli and activities. Fixations and saccades are measured to images in different areas on the monitor. Smooth pursuit of slow-moving stimuli can be measured along with optokinetic nystagmus reflexes (Kooiker et al., 2016).

Eye Gaze and CVI

Multiple aspects of CVI make eye-gaze access for AAC difficult, including apraxic eye movements, limited fixations, short visual attention, visual field deficits, and the crowding effect. Modifications and individualizing the eye-gaze device to the participant can address some of these deficits; however, the effectiveness of the system may be impacted. Modifications such as programming the system to track only the more reliable eye and increasing or decreasing dwell time can be made (Tobii Dynavox, 2015). The vocabulary set can also be modified by increasing background contrast and use of color and moving icons to adapt to visual field deficits. Finally, an individual's attraction to light can be utilized by lowering the lighting in the room and increasing screen brightness to attract attention to the screen.

AAC Teaching Strategies

When an individual learns to communicate with an AAC device, instruction on multiple levels must occur to begin to develop communicative competence. Light (1989) proposed four areas of communicative competence in AAC: operational, linguistic, social, and strategic. To gain operational competence, the individual must learn how to operate the device through their access method. Linguistic competence must also be taught so the individual understands the linguistic properties of the system (the symbols and organization of vocabulary) and can use the symbols expressively. The individual must also learn how to communicate for a variety of different functions by developing social competence. Finally, strategic competence must be developed so the individual has the necessary coping strategies to communicate using AAC. Communication competence can be achieved when these competency areas are gained and integrated into communication. Therefore, instruction in these areas should be taught together when possible so the individual learns to integrate these areas of communication (Light, 1989).

There are multiple methods for instructing individuals to use AAC to communicate. Some effective methods include incidental teaching and language modeling, which model the way that infants learn language through their environment (Beukelman & Mirenda, 2013; Hart & Risley, 1982). During incidental teaching, the communication partner sets up the environment to elicit communication from the individual who uses AAC. Some incidental teaching strategies include expectant time delay (waiting for the individual to respond while looking at him/her; Kozleski, 1991) and interrupted behavior chain (unexpectedly stopping an activity or action to elicit a response; Carter & Grunsell, 2001). A series of prompts are often used, along with incidental teaching strategies, and presented in a least-to-most hierarchy where the least amount of support is given first, followed by progressively more support, until the desired behavior is achieved. Presenting prompts in a least-to-most support order allows the communication partner to determine the necessary amount of assistance the individual needs to demonstrate the communicative behavior (Ault & Griffen, 2013). The partner also provides contingent responses to any communication from the individual who uses AAC. The communication partners of the individual learning AAC are also encouraged to provide many models on the device using aided AAC input. During aided AAC input the communication partner models their utterances on the device while also speaking them aloud. Aided AAC input has been found to be effective in teaching expressive language in AAC (Allen et al., 2017; O'Neill et al., 2018).

These instructional methods paired together can provide instruction in linguistic and social competence. Instruction in social competence should teach a variety of communicative functions through modeling, incidental teaching, and aided AAC input. Some initial communicative functions that are often taught in AAC are choice making, requesting, rejecting, and social interactions. Social interactions include introducing a topic, providing contingent responses, and asking partner-focused questions (Beukelman & Mirenda, 2013).

For many children who access their AAC devices through direct access, the modeling provided by the communication partner during aided AAC input teaches operational competence. However, for those who require switch or eye-gaze access, additional instruction is needed to ensure operational competence. There is limited evidence on best practices for teaching operational competence of eye-gaze access. This study provides a feasibility case study into a systematic method for teaching eye-gaze access and subsequent instruction in the areas of linguistic and social competence.

Despite the limitations of eye-gaze access for individuals with CVI, it was determined to be the best option in AAC access methods to pursue for the participant in this study, Jacob. Therefore, a two-part intervention was designed and implemented. The first phase was designed to teach the operational skills necessary for eye-gaze access of communication software through two eye-gaze training programs. Jacob would need to gain the visual skills of accessing the majority of the screen, visually scanning the screen for a target, and fixating on a target for a sufficient duration of time. Once these visual skills were obtained, the second phase provided instruction on operation of the communication software, the linguistic properties of the device, and the social context of communication. This investigation sought to answer two research questions. (1) Can two eye-gaze training programs be used to train an individual with CVI and CP to obtain the visual skills necessary to access an AAC system through eye gaze? (2) Once the necessary visual skills are obtained, can an individual with CVI and CP learn to communicate using communication software on a Tobii I-12 system?

TARGET AUDIENCE AND RELEVANCE

This work is relevant for practitioners and families who support individuals with complex communication needs and CVI and those that support other individuals who use eye-gaze access for AAC. The intervention discussed targeted both visual behaviors and communication and is pertinent for a variety of providers. Some individuals with complex communication needs are left with little to no method of formalized communication due to the limited access methods for AAC that fit their needs. This article demonstrates the promise of currently available eye-gaze training programs in teaching the visual skills necessary for eye-gaze access for an individual with CVI. The importance of presuming competence when working with individuals with complex communication needs is also demonstrated by Jacob's progress and quick acquisition of communication through the device. This article provides a framework for approaching the introduction of eye-gaze access with individuals who display symptoms of CVI.

METHODS

Participant

Jacob was a 14-year-old male with diagnoses of a chromosome 13 q subtelomeric deletion, encephalopathy (static) with microcephaly, CP, quadriplegic, developmental delays, seizure disorder, CVI, esotropia (a turning-in of the eye), and astigmatism. At the time of intervention, he had no reliable systematic means of communication and communicated through laughing, crying, vocalizations, facial expressions, and body language (i.e., turning his head away for dislike and waving his arms for excitement). Jacob presented with athetiod movements, spontaneous slow and involuntary movements that may be writhing and sudden (Victorio, 2020), leading to minimal voluntary control of his limbs. He presented with general low tone and his posture varied day to day, sometimes requiring a chest support for his wheelchair. It was not clear what Jacob's cognitive abilities were, as his physical and sensory deficits inhibited accurate assessment.

In addition to his motor and speech impairments, Jacob had multiple disorders impacting his vision, including CVI, alternating estropia, and astigmatism. The severity of Jacob's estropia was reduced through surgery, and he wore glasses to correct his astigmatism. A functional vision evaluation was completed a year prior at an outside location. Jacob's level of CVI was not rated in the evaluation report, but the report did provide a description of his performance on functional vision tasks. Results indicated that his nearsighted visual acuity was best within 6–12 inches, and he could perceive people up to 2 to 3 feet away. Fixations were observed to brightly colored, 4-inch pictures when presented within 12 inches of his face and when he was given auditory cues. Visual field deficits were noted in the upper, lower, and right visual fields when tracking a light source. Jacob was observed to reach for objects while looking away, which affected his accuracy. The recommendations from the assessment included decreasing background noise in his environment, using auditory cues to augment his visual input, and using motion to capture his visual attention. Jacob's auditory skills had been previously screened through auditory brainstem response testing and tympanometry. These measures indicated no abnormalities. Concerns regarding his functional hearing have been noted, but his auditory response is difficult to assess due to his limited ability to respond.

Jacob received a variety of services through the school, including speech and language intervention, occupational therapy, and indirect vision services, and he was included in general education for half of each day. His Individualized Education Program focused on increasing Jacob's ability to communicate through visual fixation, touching an object, and imitating movements; and on increasing his knowledge of cause-and-effect relationships. His vision-related goals were visually fixating on a book or iPad after a pause to indicate engagement, and combining visual fixation and touch on an iPad. Visual adaptations made at school included simplifying visual input, enforcing routines, and pairing visual information with auditory cues.

A comprehensive AAC assessment was completed by the authors with Jacob over the course of three separate days. Jacob had a previous AAC assessment 5 years prior with the second author in which a BIGmack switch and an Ultimate switch were trialed. Jacob activated a toy with both adaptive switches and used the BIGmack switch to indicate color. He had more difficulty when using the switches with auditory scanning for purposeful communication. During the most recent 3-day assessment, both switch and eye-gaze access were assessed. Four devices were trialed with eye-gaze access and two devices were trialed with auditory scanning, including a high-tech and a mid-tech device. During the eye-gaze trials and high-tech switch access trials, a board of 4 brightly colored symbols that displayed highly preferred activities was used. The Ultimate switch was used during the auditory scanning trials and was trialed in several positions. Jacob attempted to activate the switch several times, and the best location was determined to be 18 inches from the torso just left of midline. He successfully communicated "more" during a music activity and identified colors. Each purposeful communication act required multiple cycles through the options, and mishits occurred frequently. Activating the switch required great physical effort from Jacob, and he expressed frustration.

During trials with eye-gaze access, he directed his eyes toward the screen and attempted fixations to icons. He had difficulty maintaining his fixation long enough to make the selection. Due to the length of time and amount of physical effort required for auditory scanning, it was decided to first try eye-gaze training to determine if he could gain the skills to use eye-gaze access for AAC. The Tobii I-12 device was selected for the intervention as it was the largest screen available at the clinic and was compatible with multiple eye-gaze training programs.

The Intervention

The intervention consisted of 58 half-hour sessions over the course of 7 months. Sessions ranged from one to four times a week with a median frequency of twice weekly. The study consisted of two phases. Jacob was first taught the visual skills necessary to access the AAC device for communication in phase 1 through eye-gaze training programs across 31 sessions. Once Jacob demonstrated the visual skills of gaze to the majority of the screen, dwell to select, and smooth pursuit through the mastery of set levels in the eye-gaze training programs, phase 2 began. The purpose of phase 2 was to teach Jacob to communicate using the Tobii Communicator 4 software and lasted 27 sessions. The progression of the sessions was tailored to Jacob's needs and rate of learning.

Environment and Positioning

All sessions were completed in a windowless therapy room at The Schiefelbusch Speech-Language-Hearing Clinic at The University of Kansas. Visual distractors were removed from the walls, and the only room lighting was a lamp behind Jacob that provided the level of lighting necessary for the eye tracker. His wheelchair was placed at a 10-degree angle with a headrest and vest for support. The Tobii I-12 was placed on a hospital rolling mount 19 inches from Jacob's eyes and approximately 5 degrees left of center. This position was determined by using the track status function of the device to provide feedback on the placement. This position provided the best reading and utilized Jacob's unaffected left visual field. It should be noted that the ideal positioning of the Tobii I12 is 23.5 inches from and parallel to the user's eyes (Tobii Dynavox, 2015). The closer distance and slight angle could affect the gaze readings and heat maps collected during this study, but this positioning remained the same throughout the study. Room and positioning consistency was maintained for all but three sessions to improve visual attention. The clinician used her position in the room to direct Jacob's attention. During phase 1 she sat on his left side, and switched to the right in phase 2 to attract his visual attention to his right visual field. The clinician also stood behind the eye tracker on days when Jacob portrayed low visual attention to direct his visual attention back to the screen.

AAC Device and Programs

Calibration was attempted multiple times throughout the study using multiple different stimuli. Sufficient data for calibration was never achieved, so the clinician calibrated the device to herself sitting in the same position as Jacob. This is not best practice, but it was the only option for the participant. After Jacob demonstrated the skill of dwell to select in phase 1, several dwell times were trialed in the beginning of phase 2. A 300-millisecond dwell time was the most successful and was used for all of phase 2.

Eye-Gaze Training Programs. The eye-gaze training programs used in phase 1 of the intervention were Look to Learn (Sensory Software International Ltd., n.d.) and Sensory Eye-FX (Sensory Guru, 2012). These programs were chosen as they were the only commercially available programs that targeted eye-gaze skills in a progressive way at the time this study was conducted. Both programs are designed to progress the user through multiple levels of activities through which eye-gaze skills are acquired and improved. It was determined to trial both programs, as they offered different benefits. Sensory Eye-FX contained more activities with high contrast (colored objects on black backgrounds), while Look to Learn contained activities with more auditory stimulus and complex, colorful images. Look to Learn had 40 activities across five skill areas (8 activities per level; Sensory Software International Ltd., n.d.) while Sensory Eye-FX had 30 activities across five levels (6 activities per level; Sensory Guru, 2012).

The programs teach similar skills, although the order of progression differs. Table 1 provides descriptions of the 5 levels of each program, the skills targeted in those levels, and the corresponding activities. Both programs continue to target the accuracy of the user's fixations throughout the 5 levels and improve upon their eye-gaze skills. However, it was determined that once the user had mastered level 2 of Look to Learn and level 3 of Sensory Eye-FX, he had demonstrated the eye-gaze skills necessary to operate the AAC device for communication. Those skills include accessing the majority of the screen, scanning the screen through smooth pursuit and fixating on an item to select it. It was decided that Jacob did not need to demonstrate mastery over the additional levels before the communication system was introduced because the icons on the device were big enough for him to target and he did not need to learn to drag and drop to operate the communication software. The eye-gaze programs continued to be used as a warm-up activity in phase 2 to continue to progress Jacob's eye-gaze skills.

Table 1: ***Eye Gaze Training Program Level Descriptions***

		Level Description	Example Activity
Level 1	*LtL	**Sensory:** Teaches cause and effect through a visual and auditory change when a fixation occurs. Some activities require fixating on a large target while others activate wherever the user looks. *Target Skills: Visual attention, fixations, smooth pursuit*	***Cannon***: When the user looks at an area of the brick wall paint is fired from a cannon on the wall. ***Egg***: When the user looks at the large egg it cracks open to show the animal inside.
	*SE	**Blank Screen Engagement**: Teaches the user to engage with the screen through a visual and auditory change when a fixation occurs. No activities require fixation on a target. *Target Skills: Visual attention, smooth pursuit*	***Sensory circles***: When the user looks at an area of the black screen a cluster of colorful circles appears and a chime plays. When the user looks away the image and sound fade.
Level 2	LtL	**Explore**: Teaches the user to fixate on all the areas of the screen. Some activities require fixation on a target fixation and targets are smaller and in more areas of the screen. *Target skills: fixation accuracy, engagement with all areas of the screen*	***Bottles***: When the user looks at one of the glass bottles lined on a shelf it smashes into pieces ***Scratch card***: When the user looks at an area of the screen the color is removed revealing another image. All color is removed to reveal the whole image.
	SE	**Object Displacement**: Teaches the user to fixate for a reaction on the screen. All activities are colorful images on a black background and some require fixating on a specific target. *Target skills: fixation accuracy*	***Dwell bomb***: When the user looks at an area of the screen for one second, multicolored circles grow and then fly all over the screen. ***Splat***: Multicolored smiley faces float on a black screen. When the user fixates on one face it squishes out and makes a fun sound.
Level 3	LtL	**Target**: Improves the user's eye gaze accuracy. The user must fixate on individual images in various areas of the screen for the effect on the object to occur. These activities get progressively harder as the user participates. *Target skills: fixation accuracy, increase visual attention*	***Shoot***: The user fixates on traditional targets in different areas of the screen to shoot it and receive points. ***Video wall***: When the user fixates on an image it plays a video. The images progress from a display of 2 then 4 then 6. on the display.
	SE	**Zoned Focusing:** Improves the user's ability to fixate on specific targets in different areas of the screen. *Target skills: fixation accuracy, engagement with all areas of the screen*	***Lights***: The user fixates on a dim light bulb to turn it on and play a musical note. The lights are spread throughout the screen.
Level 4	LtL	**Choose**: Improves the user's choice making skills. These activities show an image and at least 3 smaller images on the side of the screen (left or right depending on the activity). The user can change the look of the larger image by choosing a small image through fixation. *Target skills: fixation accuracy, choice making*	***Drummer***: The user chooses the set of drumsticks for the drummer to use by fixating on them. The man then plays the drums with the chosen sticks. ***Dinner time***: The user chooses what the man will eat for dinner by fixating on a food item.

		Level Description	Example Activity
	SE	**Active Exploration:** Encourages the user's exploration and engagement with the screen. Some focus on making music or painting while others practice targeting. *Target skills: fixation accuracy, engagement with all areas of the screen*	***Archery***: The user fixates on traditional targets displayed in several rows and it is shot down with an arrow. ***Piano***: The user plays a song by fixating on different keys on a piano keyboard.
Level 5	LtL	**Control**: Improves the detailed eye gaze skills of the user and their drag and drop skills. Some activities work on precise fixations to an image and others teach the user to fixate on an image and move it with their gaze. *Target skills: drag and drop, fixation accuracy*	***Penalty***: The user shoots the soccer ball into specific areas of the goal by fixating on it. The user can also be the goalkeeper and chooser where to dive through fixation. ***Jungle***: The user chooses an animal to add to the picture and drags it on the screen and puts it on one of the preset stars.
	SE	**Controlled Targeting**: Increases the accuracy of the user's gaze and dwell functions. Several different skills are targeted depending on the activity. *Target skills: smooth pursuit, fixation accuracy*	***Object control*****:** The user fixates on the balloon and drags it around. If fixation is not maintained the balloon falls to the bottom of the screen and pops. ***Killer bee***: A bee flies around the screen and the user must fixate on the moving bee to squash it.

Communication Software. Tobii Communicator 4 was used during phase 2 of the study (Tobii Technology AB, 2015a). The first four sessions of phase 2 used a custom designed display to determine if Jacob had acquired the necessary visual behaviors to communicate with the device. The custom display contained 6 icons with brightly colored backgrounds with contrast and the vocabulary related to high-interest activities. Jacob demonstrated the visual behaviors necessary to activate the icons on the custom board for purposeful communication. It was decided to begin to trial the Sono Flex common vocabulary user during the fourth phase 2 session because of the preset vocabulary available on the user and ability to grow as his language increased. He demonstrated the ability to use the Sono Flex user from the first session despite its lack of high-contrast, colored backgrounds. The Sono Flex common vocabulary user contained 800 commonly used words with the home screen having direct access to core vocabulary and 4 context buttons. The user had 4 rows and 6 columns for a total of 24 icons that were one inch by one inch in size. The right column on the home screen contained context pages that could be interchanged. The reading and television context pages were used during structured activities. These context pages contained words specific to that activity. Icons were on white backgrounds with a colored border coded with the Fitzgerald key to indicate word type (Tobii Technology AB, 2015a). In the video and reading context pages, only the relevant words for the activity were displayed and the rest were hidden in the initial sessions. The relevant words included action words (play, stop, go, read) and the book or video options for him to choose from. As he demonstrated use of these words over multiple sessions, the other words on the page were unhidden at a rate of several per session.

Tobii Gaze Viewer. The Tobii Gaze Viewer program was used to record eye-tracking data during each session (Tobii Technology AB, 2015b). The software collected all fixations made during a session and displayed them through heat maps and gaze plots superimposed over the activity. The heat map demonstrated the areas Jacob fixated on the most and the areas he did not look at. The gaze plot showed the number and order of fixations that occurred in the session (Tobii Technology AB, 2015b). These measurements were used to assess Jacob's visual attention and functional access to different areas of the screen.

Phase 1

Phase 1 consisted of 31 half-hour sessions focused on teaching Jacob the visual skills necessary to access an AAC device through eye gaze. Sessions began with 15 minutes of activities from Look to Learn followed by Sensory Eye-FX activities for 15 minutes. The intervention began with level 1 in each program.

Jacob remained in a level of each eye-gaze training program until he *mastered* five of the activities in the level. Jacob's performance was evaluated through a worksheet modified from the Look to Learn software. The worksheet ranked Jacob's demonstration of the targeted eye-gaze skills for the activity as either not demonstrated, developed, or achieved. His motivation, enjoyment, overall success, and level of facilitation needed were all rated on a scale of 1 (low) to 5 (high). The goal was for Jacob to demonstrate the targeted eye-gaze skills with limited assistance from the clinician. An activity was considered *mastered* when Jacob received a score of *achieved* on the targeted eye-gaze skills for the activity, a 4 or above on the levels of motivation, enjoyment, and overall success, and a score of 3 or below on the level of facilitation. The activities were repeated until Jacob mastered five activities in the level and could move to the next level in the program. This criterion of five mastered activities was modified to four activities in level 2 and three activities for level 3 of Sensory Eye-FX as Jacob was demonstrating refusal for the remaining unmastered activities by turning his head away. These activities were less visually and auditorily stimulating than other activities, which may have decreased his motivation. The next level was trialed with the option to move back to the previous level if he was unable to master the activities. He did demonstrate mastery over some of the activities in the following level in both occasions.

Intervention Strategies. The teaching strategies used during phase 1 of the study were modeling and visual and verbal cues. The clinician modeled a new activity by activating the screen with her finger and completing the task. General verbal cues were used to direct Jacob's visual attention to the screen (e.g., look at the screen to make the picture show up). Specific verbal cues were used to direct his gaze to specific areas of the screen to complete the task (e.g., look at the man with the silly face in the corner) and provide auditory information to supplement the visual. Finally, visual cues were used to attract Jacob's vision to specific parts of the screen by the clinician waving her fingers or an object in front of the target area of the screen.

Fidelity. Phase 1 sessions were administered by two different clinicians, the first author and a doctoral student who was a speech-language pathologist with AAC experience and was trained in the intervention protocol. Fidelity of the room configuration, device positioning, and administration of the eye-gaze programs were judged by an independent rater for 20% of phase 1 sessions for an average reliability of 93%. Reliability of scoring of activities was attempted from video recordings; however, due to the low lighting in the room, the recording of the screen was not sufficient to conduct offline scoring.

Phase 2

As mentioned previously, Jacob began phase 2 after mastering level 2 of Look to Learn and level 3 of Sensory Eye-FX, with reduced mastery criteria of 3 mastered activities. Phase 2 consisted of 27 half-hour sessions with a focus on teaching Jacob to use the Tobii Communicator 4 software to communicate. Each phase 2 session consisted of a five-minute warm-up activity on the eye-gaze training programs, conversational instruction, and a requesting/choice making activity. The conversational instruction used the full vocabulary set available on Sono Flex. The clinician used aided input and least-to-most prompting to teach Jacob different pragmatic functions and the linguistic properties of the device. The requesting/choice making activity used books and videos that were highly preferred as determined by parent report and Jacob's expression of excitement through body movement. During this activity, appropriate context pages of the device were used. Jacob could choose which book or video he wanted from programmed vocabulary in his device.

Jacob's utterances were transcribed by the clinician, and the pragmatic function of each utterance was coded. The transcripts were then analyzed using the Systematic Analysis of Language Transcripts (Miller & Iglesias, 2015). The pragmatic functions coded were initiations, comments, answering questions, choices, asking questions, and requests. Initiations and comments were both independently made and differed based on context with comments relating to the activity or topic of discussion and initiations were unrelated to the current discussion. Answering questions and choices were both in response to the clinician's prompt. Asking questions was defined as using the question words on the device. Finally, requests were made independently and demonstrated a want or need. Frequency counts were gathered for all of the pragmatic functions.

Intervention Strategies. The primary teaching strategies used in phase 2 of the study were aided AAC input, incidental teaching, expectant wait time, verbal prompts, and verbal and visual cueing. Table 2 shows the instructional steps of each activity during phase 2. Each time a new page was introduced, the clinician would model the new vocabulary by pointing and labeling each of the icons on the page to teach Jacob the vocabulary and cue him to the location of each word. During the conversational instruction, the clinician used aided AAC input by saying a sentence or question aloud while activating 1–3 key words of the sentence on the device through touch. This was used to demonstrate a variety of pragmatic functions (questions, initiations, etc.) and multi-symbol utterances. After the clinician asked a question or made a comment, she would provide 5–7 minutes of expectant wait time for Jacob to respond. If Jacob did not respond, a least-to-most prompting hierarchy began. The hierarchy starts with providing the least amount of support and gradually adds more support if the child does not respond to the previous prompting level. The first level was opening the relevant page of vocabulary for Jacob and providing wait time. In the next level, the clinician labeled several icons as possible responses for Jacob, followed by wait time. Finally, if no response was made, the most support was given by modeling a response and then a new topic was introduced. When Jacob did provide a response or initiation at any point in this prompting hierarchy, the clinician would prompt him to expand on his utterance and provide suggestions on how to elaborate. (view Table 2 on following page)

Table 2: Prompting Hierarchy of Teaching Strategies Used in Phase 2

Description of Prompt	Example for Conversation Interaction	Example for Choice Making Activity
General prompt or specific question using aided AAC input + wait time		
The clinician asks a general or specific question to Jacob and models the key words on the device while speaking the sentence aloud (noted in bold). Then the clinician waits for several minutes for Jacob to respond while the device is on the home page.	"**What** do you want to **talk** about" "**What** did you **do** today?	"Do you want to **read** a book or **watch** a video?"
Open relevant page of vocabulary + wait time		
The clinician opens the relevant page of vocabulary Jacob could use to answer the question and waits for several minutes.	Clinician opens the actions page. "These are actions that you might have done today"	Clinician opens the video page "These are videos you might want to watch. What do you want to watch today?"
Label several icons as possible responses + wait time		
The clinician labels several icons on the relevant vocabulary page as possible responses for Jacob to communicate.	"Maybe today you worked (points to work) at school or played (points to play) in the park or watched (points to watch) a movie. What did you do today?"	"Do you want to watch the Lion King, a truck video, or the Lego Movie?" Points to each as she says them.
Model a possible response + introduce a new topic/ starts the activity		
The clinician models a response to the question using aided AAC input. In conversation practice a new topic is then introduced and the hierarchy starts from the beginning. In choice making the activity the clinician chose is started.	"Today I **work**ed on a paper" "How are you feeling today?"	"Let's watch **the Lion King**".
If at any point during the hierarchy Jacob responds his utterance is repeated. During conversation he is prompted to elaborate and during choice making his choice in activity is started.		
The clinician repeats the word Jacob says and puts it in an utterance and prompts for more information.	J: work C: "Oh you worked today. What did you work on?"	J: truck video. C: "Okay let's watch the truck video"

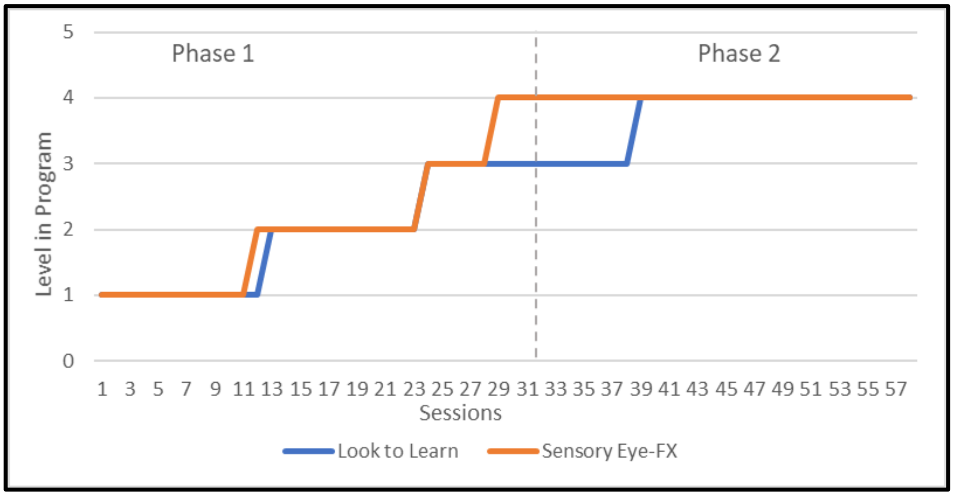
During the requesting/choice making activity, Jacob was presented with several options to choose from. A similar least-to-most prompting hierarchy was provided. First, the context page was opened with relevant vocabulary; next, the possible choices were labeled; and finally, the clinician modeled a choice and began that activity. During the reading of the book or playing of the video, the activity would stop after several minutes to provide an incidental teaching opportunity. Suddenly stopping the activity allowed Jacob the natural opportunity to ask for more or choose another option.

Visual and verbal cues were also used to teach Jacob the length of fixation needed to activate an icon. The visual cue used was a setting on the device in which a red circle that fills in a clockwise motion indicates the length of fixation needed for selection. Jacob had to fixate until the circle was completed for the word to be selected. If Jacob was not able to maintain his fixation for the set 300ms, the clinician provided verbal cues and encouragement to teach Jacob how long his fixation needed to be maintained.

RESULTS

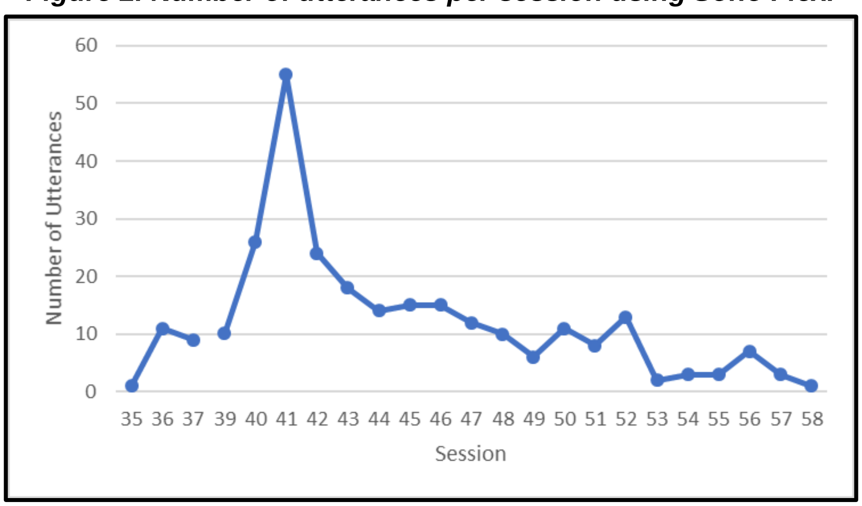
To answer the first research question, the activities and levels mastered on the eye-gaze training programs were assessed. At the end of phase 1, Jacob had mastered the first three levels on the Sensory Eye-FX eye-gaze training program and the first two levels of Look to Learn. By mastering these levels of the eye-gaze training programs, Jacob had demonstrated the visual skills necessary to access an AAC system through eye gaze. Figure 1 shows the rate of level mastery for each program. During the 5-minute warm-up activities in phase 2, Jacob continued his progress on the programs and mastered level 3 of both programs. He also mastered 4 activities in level 4 of Look to Learn and 3 activities in level 4 of Sensory Eye-FX.

Figure 1. Level mastery in eye gaze training programs.



Jacob’s number and type of utterances were used to analyze the second research question. Figure 2 presents Jacob’s number of utterances produced per session after the Sono Flex user was introduced during session 35. Using Sono Flex, he produced an average of 12 utterances per session for an overall total of 345 words and 152 different words.

Figure 2. Number of utterances per session using Sono Flex.



The majority of Jacob's utterances were 1 word in length. He also generated 11 two-word combinations and 1 three-word combination. An excerpt of the transcript from session 43 is presented in Table 3 that demonstrates Jacob's functional communication using the device.

Table 3: Sample Transcripts from Phase 2 Sessions

C = Clinician **J = Jacob**
Session 41- Initiations and word combinations
J: Start. C: Okay I will start reading. (Started reading the book) J: Read. C: Yes I am reading the book. J: I turn_page. C: You want to turn the page? Ok let's see (guided his hand to turn the page). J: You listen. C: Okay you want me to stop and listen to you.
Session 43- Expression of feelings and navigation
C: What else did you do today? J: Drink. C: You had something to drink? Or do you want a drink? J: Drink. C: You want a drink. J: (navigated to feelings page) Frustrated (child tears up). C: You're frustrated because you can't drink. C: I'm sorry buddy I can't give you something to drink right now (child cannot intake anything by mouth due to aspiration of liquids).
Session 52- Example of choice making
C: What do you want to watch? J: Lego_Movie. J: Show. (Clinician plays LEGO movie for several minutes and then stops it) C: Do you want to play (points to play) more of the movie or go to the next (points to next) movie? J: Truck_Video. C: Okay let's watch the truck video.
Session 54- Examples of Answering Questions
C: How are you today? J: Tired. C: What did you do for Thanksgiving? J: Feel. C: Who did you see on Thanksgiving? J: Uncle.

Jacob communicated for a variety of social functions as seen in Table 4. The most frequent pragmatic functions used were comments and initiations. His comments were often a statement of feeling or an observation of the environment.

Table 4: Frequency of Pragmatic Functions

Pragmatic Function	Total Number Used in Phase 2
Initiation	55
Comment	51
Answering Questions	45
Making Choices	45
Asking Questions	14
Requesting	4

The number of gaze points recorded during the entire 30-minute session is used to determine if a pattern is seen in Jacob's number of fixations and visual attention during the intervention. Jacob averaged 166.8 gaze plots per session over the course of the study. Figure 3 depicts the number of gaze points recorded at each session. [Insert Figure 3]. High levels of variability are seen in Figure 3, so to better understand general trends, the average number of gaze points every three sessions is also reported in Figure 4. Despite the variability, a trend emerged that Jacob had fewer sessions with gaze point frequencies below 50 in phase 2 (*n* = 2) than in phase 1 (*n* = 11).

Figure 3: Number of gaze points per session.

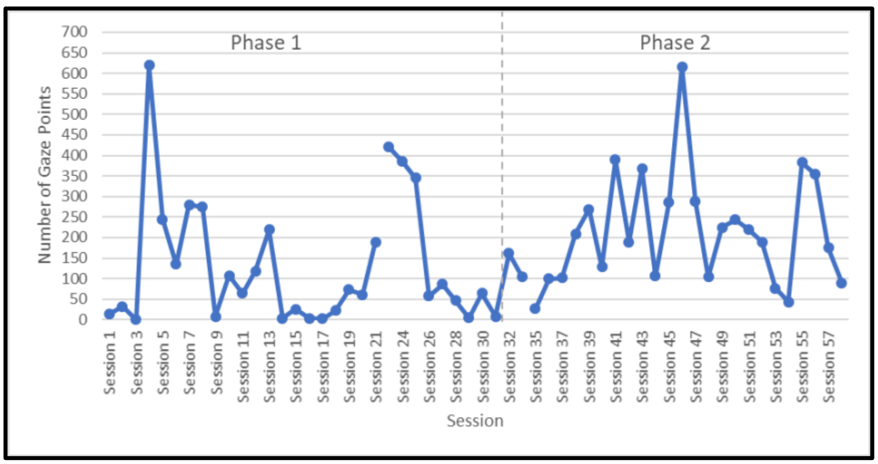
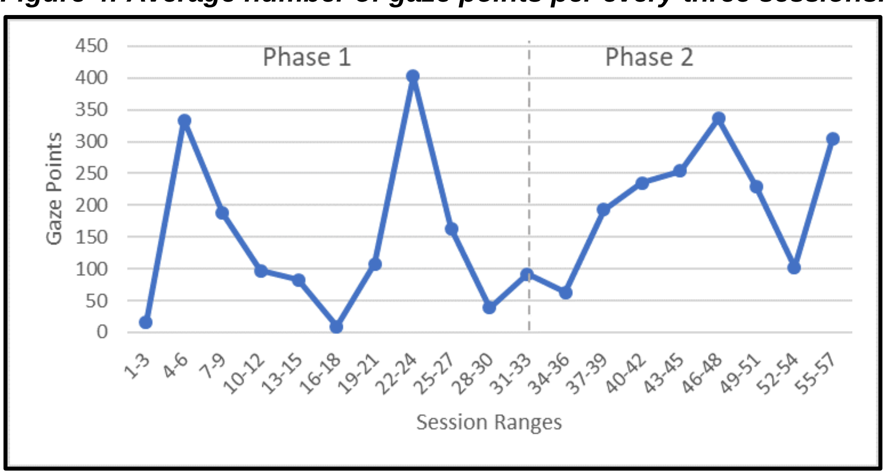


Figure 4: Average number of gaze points per every three sessions.



The other trend that is visible in these graphs is an increase in gaze points for several sessions, starting at session 4, followed by low gaze-point frequencies for another several sessions. This pattern is demonstrated throughout the intervention.

DISCUSSION

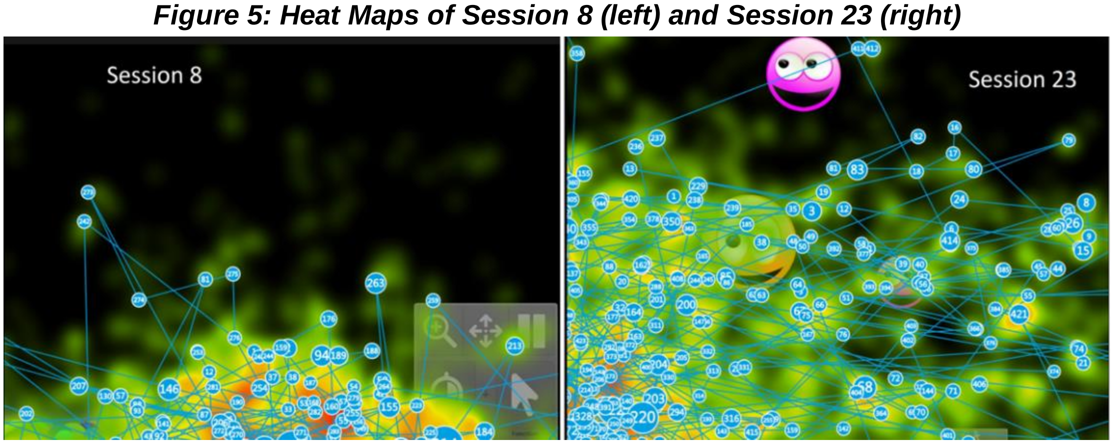
This feasibility case study answered the two research questions posed: (1) The two eye-gaze training programs trained Jacob in the visual skills necessary to access an AAC system through eye gaze; (2) He also learned to communicate using communication software on a Tobii I-12 after the necessary visual skills were obtained. Due to the nature of Jacob's disability, his level of alertness, attention, and motivation varied, and that variability is seen in the data. However, Jacob demonstrated the necessary visual skills to progress to level 4 of both eye-gaze software programs and communicate on the Tobii I12.

Functional Gains in Eye-Gaze Skills

Throughout this intervention, Jacob improved in his ability to use his vision to access the Tobii I-12 through eye gaze. Improvements were seen in his visual attention, length of fixation, access to a greater visual field, and demonstration of smooth pursuit. Improvements and variability in Jacob's visual attention and fixations were demonstrated by the number of gaze points on the screen. Although no baseline sessions were gathered, a marked increase in gaze points is seen at session 4 compared to the first 3 sessions. A pattern of several sessions of high gaze points followed by several sessions of low gaze points is then seen. This fluctuation was due to multiple factors, including attention, alertness, and interest in the activities on the programs. However, in phase 2 there is an overall improvement in visual attention, demonstrated by the drop in the number of sessions containing less than 50 gaze points. Functionally, this was demonstrated by Jacob's ability to dwell to select vocabulary to communicate in phase 2.

Improvement in Jacob's visual field was demonstrated through heat maps and fixations to various icon locations. Initial session heat maps revealed gaze primarily in the bottom and left side of the screen. As treatment progressed, he accessed the middle and right side of the screen during activities as seen in Figure 5, and by the end of phase 1, he accessed the top of the screen.

Figure 5: Heat Maps of Session 8 (left) and Session 23 (right)



Although these two images depict different activities with different skill targets (screen exploration versus fixating on an image), they were chosen because both contained colorful images on a black background. This progression in visual field was seen in phase 2 by Jacob's activation of vocabulary in many different areas of the screen to communicate. Finally, improvements in smooth pursuit were measured through his performance on activities that required the tracking of an object across the screen. Jacob progressed from only activating the screen in isolated areas to moving his eyes across the screen in a more continuous motion for longer periods. This functionally allowed him to scan more of the screen during more complex activities and to scan the vocabulary set for the word he desired.

Functional Gains in Communication

Prior to the intervention, Jacob communicated via facial expressions and some body movements. In the AAC evaluation conducted, Jacob directed his attention to a screen, but did not fixate long enough to activate an icon. During phase 2 of the intervention, Jacob functionally communicated with the clinician on the first day. Jacob progressed in his operation of the device, dwelling to select words and demonstrating some independent navigation of the dynamic display. Linguistically, Jacob communicated with an average of 12 utterances in 25 minutes per session. He accessed a variety of vocabulary with 152 different words used during the 24 sessions with Sono Flex. He also began combining words into phrases, with a total of 11 two-word phrases and one three-word phrase produced. These combinations often required several minutes of pause time between words. Finally, in the area of social gains, Jacob communicated for a variety of purposes during the phase 2 sessions, including: commenting, stating his feelings, initiating, answering questions, making choices, asking questions, and requesting.

Clinical Implications and Future Work

When working with individuals with multiple disabilities who require AAC, all avenues should be explored to ensure that their communication needs are met. This may involve training the foundational skills to use a particular access method. This study demonstrates a first step in developing an evidence-based program for teaching the skills necessary for eye-gaze access in individuals who use AAC. Further work is needed to develop a more systematic approach to teaching these skills and to evaluate the use of eye-gaze training programs with multiple populations. Future research and clinical work should use other methods of data documentation to capture functional changes in skills throughout the intervention. This could be done with using a specific assessment activity that elicits the visual skills necessary for eye-gaze access that is administered at regular intervals during the intervention and at baseline. This study lacked a baseline phase, so it was difficult to determine if the gains were a result of the intervention. Future research should administer baseline activities to better understand the individual's skills prior to intervention. Reliability scoring should also be conducted on participant performance; this was lacking in the current study.

When designing, implementing, and modifying a similar intervention, the individual's preferences, along with their visual strengths and weaknesses, should be considered. Jacob's preferences were considered in this study by altering the mastery criteria for levels 2 and 3 of Sensory Eye-FX, as he demonstrated nonverbal signs of refusal for the activities. These activities contained less visual and auditory stimuli and had a lack of color contrast. His preferences and skill acquisition were both considered by trialing the next level with the opportunity to go back to the lower level if activities were not mastered. It is important to consider the individual's preferences in order to keep them motivated and progressing.

In working with individuals with CVI, it is essential to obtain a detailed and recent functional vision report, and to work with a multidisciplinary team (Lueck et al., 2019) when designing and implementing your intervention. A detailed vision report will give you crucial information regarding the visual behaviors of your client, which are important to consider for device setup and intervention planning. Regular assessment of the individual's functional vision is also crucial, as changes may occur due to the neuroplasticity of the brain (Martin et al., 2016). In this study, the lack of a more detailed and recent functional vision assessment was a weakness and led to the need of more trial-and-error with the types of stimuli used.

There are multiple AAC systems on the market. This study used devices and programs that were current at the time but have since been updated. Providers should evaluate the devices and programs currently available in relation to their clients' strengths and needs to determine the best fit. They should also keep in mind the individual's color preferences, contrast sensitivity, perception of movement (Good et al., 2001), visual attention, perception of complex visual images, and visual field when evaluating and trialing devices and programs.

Adaptations can be made to the AAC system to capitalize on the individual's visual strengths and accommodate for weaknesses. The length of fixation necessary to select a word can be adjusted through the dwell-time setting. The individual's visual field on the device can be assessed through heat maps, and then icons outside the visual field can be moved. Many communication programs contain options for customizing the display and/or icons to increase contrast and utilize color. Finally, the teaching strategies used should also be determined through the individual's visual profile, such as using motion as a prompt or to attract visual attention, and supplementing the visual information with narration and verbal prompts. This study accommodated for visual field deficits by moving the screen, and by reducing the number of icons on the screen to reduce image complexity. Edits were not made to the system to accommodate for contrast sensitivity and color preferences. Future work should consider all of these areas when setting up the device.

When teaching communication in AAC, it is important to consider the instruction in the areas of device operation, language, and social communication. Instruction should occur on all three of these areas to allow for integration and successful communication (Light 1989). Evidence-based teaching strategies should be applied to all three areas and allow for opportunities for independent communication, and support should be increased as needed. This includes providing sufficient wait time between prompts (Kozleski, 1991), as the individual may need longer to process the visual information and make a selection than a user with typical vision. It is also important to consider that operational instruction must continue to occur once the communication system is introduced, in order to transfer the skills learned from the eye-gaze training programs to the communication system.

The result of the instruction on the individual's language and social communication outside of the therapy sessions should also be documented through parent surveys. A weakness of this study was the lack of data collection of the prompting levels needed to elicit visual behaviors and communication. Future work should document the level of support needed for communication in order to determine if the individual is becoming more independent. The number and location of icons hidden on each page should also be documented in detail along with when the icons were unhidden and the effect of the additional vocabulary on the participant’s communication. Furthermore, instructional fidelity should be documented by collecting high-quality recordings of sessions and scoring fidelity with blinded coders.

OUTCOMES AND BENEFITS

This feasibility case study provides a first step in developing an evidence-based intervention to teach the eye-gaze skills necessary to access an AAC device for individuals with CVI. The intervention incorporated strategies from the CVI literature and Jacob’s individual visual strengths and deficits. Jacob gained the visual skills necessary to access the AAC device and learned to communicate for a variety of functions. The eye-gaze training programs used show promise in teaching eye-gaze skills, but activities should be evaluated with the individual’s preferences and visual strengths and deficits in mind. Jacob learned to communicate on a user that contained one-by-one-inch icons and lacked visual contrast. This work demonstrates the importance of presumed competence. Individuals with limited access options for AAC should be taught the necessary skills for access. Further research on eye-gaze training programs and interventions to teach eye-gaze access for those with CVI is needed.

DECLARATIONS

This content is solely the responsibility of the author(s) and does not necessarily represent the official views of ATIA. No financial disclosures and no non-financial disclosures were reported by the author(s) of this paper.

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