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Eye Gaze 101: What Speech-Language Pathologists Should Know About Selecting Eye Gaze Augmentative and Alternative Communication Systems

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People with complex communication disabilities along with severe physical disabilities commonly need assistive technology to support access to augmentative and alternative communication (AAC) devices. Eye gaze techniques have become one of the solutions available to solve their access issues. An AAC system that can be used with eye gaze technology usually involves a computer-based device and an eye-tracking device. Although applying eye gaze as an alternative access method for AAC is promising for many people with both complex communication disabilities and physical disabilities, knowledge and skills of the clinician in gathering evidence to decide an eye gaze access is critical to achieve the desired outcome of effective communication. This article will review previous research evidence related to eye-tracking technologies and eye gaze techniques applied with different populations and, then, provide clinical guidance to readers.

Types of Eye Tracking Technology

The predecessors of current eye-tracking technologies can be traced back to the early 1900s, and several different eye-tracking technologies have been investigated (Wade & Tatler, 2005). The three eye-tracking technologies that are commonly used in commercial applications include (a) videooculography, video-based tracking using head-mounted or remote visible light video cameras; (b) video-based infrared pupil–corneal reflection (IR-PCR); and (c) electrooculography (Majaranta & Bulling, 2014). Besides common commercial products, researchers have also built open-source eye-tracking software that can be used with a regular webcam, such as the ITU eye tracker (San Agustin et al., 2010). In this article, we will focus on clinical applications using IR-PCR technology because this technology is the most common eye-tracking technology that speech-language pathologists (SLPs) use in their daily practices (e.g., Products from Tobii-Dynavox, LC Technologies Inc., and Prentke Romich Company). Due to many commercial eye-tracking devices being on the market, applying evidence-based principles is important for selecting a proper eye-tracking device paired with an augmentative and alternative communication (AAC) system to ensure the best outcomes of our services.

IR-PCR technology uses a camera and an infrared (IR) light source to illuminate the eyes and, then, uses the reflections on the cornea as a reference for detecting eye gaze and movements (Majaranta & Bulling, 2014). By controlling an IR source, this technology can provide both a bright pupil and a dark pupil effect. The bright pupil method uses the reflection from the retina to detect the eyes. When using this method, an observer can see a white/bright effect in the user's eyes. Although the bright pupil effect method enables the eye-tracking software to easily analyze the pupil image, this approach does not work well in bright daylight or outdoor light (Al-Rahayfeh & Faezipour, 2013; Majaranta & Bulling, 2014; Majaranta & Räihä, 2002). In comparison, the dark pupil effect method uses a camera to capture the eye image without an IR resource. Therefore, an observer will see a dark pupil effect in the user's eye. Some issues may be observed when users have dark brown eyes because the dark eye color will create a low contrast between a brown iris and the black pupil (Al-Rahayfeh & Faezipour, 2013; Majaranta & Bulling, 2014). One consideration that should be noticed is that very few studies compared the bright pupil and dark pupil effects using the latest technologies. Therefore, it is hard to evaluate if the latest eye trackers remain the difference between the two.

In addition to the two technological differences, several factors that can affect pupil detection when using an eye-tracking device need to be considered. Not only does the shape of the pupil influence use but the eyebrows, skin color, eye color, race, and eyelid interference are also potential complicating factors for some users (Arai & Mardiyanto, 2011). Besides the characteristics of each individual's eyes, several common eye disorders also affect the results of eye tracking. Those disorders will be discussed in the section on Clinical Application.

Applications to Clinical Populations

Before providing clinical guidance, research evidence on using eye-tracking technology and eye gaze techniques with AAC applications are presented. Although many clinical populations can benefit from eye-tracking technology, this article will focus on amyotrophic lateral sclerosis (ALS), cerebral palsy (CP), and Rett syndrome because SLPs may receive a higher number of referrals for these populations in a clinical setting. Up to now, studies have investigated performance, user satisfaction, and issues related to using eye gaze techniques with different populations, including individuals with ALS (Calvo et al., 2008; Hwang, Weng, Wang, Tsai, & Chang, 2014; Käthner, Kübler, & Halder, 2015; Pasqualotto et al., 2015), CP (Amantis et al., 2011; Borgestig, Rytterström, & Hemmingsson, 2016; Borgestig, Sandqvist, Parsons, Falkmer, & Hemmingsson, 2016; Man & Wong, 2007; Rytterström, Borgestig, & Hemmingsson, 2016), and Rett syndrome (Lariviere, 2014; Sigafoos et al., 2011; Stasolla et al., 2014; Townend et al., 2016).

A common concern regarding the performance of eye gaze techniques is related to rate and accuracy. Establishing and maintaining a functional communication rate is always a challenge for AAC users. Although using eye gaze techniques tends to be slower in building skills than hand/mouse access, eye gaze has similar efficiency compared with head mouse access in typical adult participants (Hansen, Tørning, Johansen, Itoh, & Aoki, 2004). Meanwhile, several studies have shown that people with ALS were able to use eye gaze techniques as their access method for spelling (Calvo et al., 2008; Hwang et al., 2014; Pasqualotto et al., 2015). However, published evidence on performance rates have been calculated differently across studies so that accurate comparison is difficult. When comparing eye gaze access to brain–computer interface access, participants with severe motor impairment, such as people with ALS, have rated eye gaze technology more efficient and usable (Käthner et al., 2015; Pasqualotto et al., 2015). Yet, these participants were still able to use eye gaze access and were not identified as "locked in." Brain–computer interface access is intended for individuals when eye gaze access has been ruled out as an option. The brief review above suggests that people with ALS or severe motor impairments can be candidates for using eye gaze techniques as an access method. However, caution is warranted to make the clinical decision to recommend eye gaze as the access method without a comprehensive assessment and without proper consideration of the various commercially available technologies.

Individuals with CP often use eye gaze techniques. One study has shown that children with CP from ages 1 to 15 were able to learn to use eye gaze technology to control their assistive technology in their daily lives (Borgestig, Sandqvist, et al., 2016). The results from parental interviews of children with CP aged 5 to 15 showed that the children were able to not only express their needs but also show their choices and self-determination and demonstrate their competence and personality using an eye-tracking device (Borgestig, Rytterström, et al., 2016). Although this evidence supports the idea that children with CP may improve their communication using eye gaze techniques to access their AAC devices, clinicians should still consider the individual's body structure and functions, abilities, and expectations. For example, two college students with quadriplegic athetoid CP reported that they were unable to activate the eye-tracking device during trials (Man & Wong, 2007). The results indicated that eye gaze technology may not be suitable for everyone with CP who is unable to directly select using a hand/finger, other body part, or head/chin stick. Therefore, consideration of all the characteristics related to an individual's body function and structures is important, in addition to evaluating their performance with different access technologies.

Finally, people with Rett syndrome have also been recommended for the use of eye gaze techniques. Rett syndrome is a unique postnatal neurological disorder caused by mutations on the X chromosome on a gene called *MECP2*. It occurs primarily in girls. Individuals with this diagnosis show a loss of cognitive, sensory, emotional, motor, and autonomic function (The International Rett Syndrome Foundation, n.d.). Eye gaze techniques have been explored as an access method using AAC for people with Rett syndrome (Townend et al., 2016). People with Rett syndrome commonly used their eye-tracking devices for cause–effect games and making choices at home and school. Some parents also reported that their children understood language better after using the eye-tracking technology (Townend et al., 2016). The results show that, at least from the parents' perspective, children with Rett syndrome can potentially improve their communication and language performance by using eye gaze techniques. Certainly, further clinical research would help in understanding the benefits of recommending eye gaze technology to people with this diagnosis.

Additional Factors

Several factors can affect the outcomes of using eye gaze techniques, which clinicians should take into consideration prior to recommending eye gaze technology. Parents have reported that increasing the amount of training and support from specialists and manufacturers was needed for their children using the technique (Townend et al., 2016). Teachers have indicated that it is important to understand what the children are trying to do and express first, so that they can better teach students using their eye-tracking device. Teachers also should avoid being too ambitious during training, so that students can engage in the learning process (Rytterström et al., 2016).

Communication rate and accuracy using this technology also could be a factor affecting the users' satisfaction. AAC speakers with acquired disabilities were often frustrated due to the slow conversation rate (Fried-Oken et al., 2006). Therefore, during the assessment process, clinicians need to consider more than the technology or devices, for example, how language is represented and generated and the message management strategies used to ensure the best communication rate or communication effectiveness.

Users' preferences must be considered as well. Simply because a client is capable of using eye gaze technology does not mean that the client will accept the technology. One example was a participant with ALS in Käthner et al. (2015). Although the participant in the study was able to use eye gaze access and also reported that the technique was the least tiring method, the participant still preferred to use a low-technology eye gaze letter board, which was a communication method that was more familiar to the participant's caregivers. Meanwhile, the research team also observed that using the low-technology board was fast, accurate, and lacked technical problems.

In summary, research and clinical evidence may support the benefits of eye gaze technology for people with complex communication disabilities. However, personal evidence gathered about the person's preferences and comfort levels may indicate that other access methods may be better supported and more functional. Additionally, high technology may be more suited for specific applications or times and, low technology, more suited for other situations and times.

Clinical Applications

After the brief review of the current external evidence on eye gaze technology, this section will provide some clinical guidance for clinicians to consider during the eye gaze technology assessment and intervention processes. Completing an evaluation using an eye-tracking device is one of the most challenging AAC evaluations to complete. SLPs must be knowledgeable in a variety of disorders and technologies. These disorders range from acquired neurological disorders, such as ALS and multiple sclerosis, to congenital disorders, such as Rett syndrome and CP. When evaluating eye gaze, SLPs should consider four body and structure factors that will impact a client's performance on the system. These factors include vision (sensory), physical status, language ability, and cognition. For the purpose of this article, we are considering that hearing acuity (sensory) is within normal limits (American Speech-Language-Hearing Association, n.d.).

Vision

Eye-tracking cameras that come with a commercial speech-generating device (SGD) are different across manufacturers. Because SGD funding requests require trial considerations of at least three different SGDs, more than one manufacturer's eye-tracking device should be considered for the trial. Clinicians and the eye gaze user want to have confidence in the eye-tracking features that benefit the user. Most of the SGD manufacturers use a camera system with an IR light to reflect the beam of the camera off the back of the retina and then back to the computer in order to determine gaze point. Several eye disorders can impact the calibration process or cause difficulties for the person during use. For example, some eye movement disorders will affect target selection features, such as dwell time and/or eye blink. Some of the most common eye deficits include cataracts, ptosis, nystagmus, alternating strabismus, cortical vision impairment (CVI), and mydriasis. Further details follow below.

Cataracts. Cataracts are one of the most common eye disorders for people over the age of 40 years. Cataracts slowly form by covering a person's lens, which can affect the way light enters the eye (Liu, Wilkins, Kim, Malyugin, & Mehta, 2017). This will also affect the way the IR light from the eye tracker reflects off the eye during calibration. The best way to compensate for this is to set the eye gaze system to use only one eye if the user has a better eye without a cataract. Otherwise, the user may need to have the cataracts removed to ensure eye gaze accuracy.

Ptosis. Ptosis is eyelid droop that partially or completely covers the pupil (Stonely, 2011). Some SGDs require the entire circumference of the pupil in order to accurately calibrate the eye-tracking camera. It is important to ask the manufacturer if their eye-tracking camera can compensate for a user with ptosis. If not, attempt to calibrate the camera to the other eye if it is absent of ptosis.

Nystagmus. Nystagmus is an eye condition in which the eyes make repetitive, uncontrolled eye movements (Lueck, 2005). These movements often result in decreased depth perception, which may affect a user's ability to accurately calibrate the SGD. If a user's involuntary eye movements occur fewer than three times per minute, then they will have a greater success rate using the system. Otherwise, nystagmus will affect the ability of the user to focus and make a selection from the SGD.

Strabismus. Strabismus is the failure of the two eyes to maintain proper alignment and work together (Haggerty, 2011). One way to compensate for a user who has strabismus is the use of an eye patch. The use of a partial nasal side patch and calibrating the eye tracker to use the nonpatched eye will improve the user's accuracy and selection rate. Our clinical experience suggests that clinicians should avoid covering the entire eye with the patch as this can be overwhelming for the user.

CVI. CVI is a visual impairment that occurs due to brain injury (Watson, Orel-Bixler, & Haegerstrom-Portnoy, 2007). CVI differs from typical visual impairments because, unlike other eye disorders, CVI is an impairment of the occipital lobes of the brain. The severity ranges and, at times, can improve with age or as the brain heals from a traumatic brain injury. Adjustments such as changing the colors of the icons to increase contrast, have been effective in helping users distinguish the icons. This is also recommended for the calibration dot and the background of the calibration screen. Likewise, changing the color of the selection marker, whether it is the mouse pointer or a high contrast outline of the intended target, will help the user identify their intended target.

Mydriasis. Mydriasis is dilation of a pupil (Braksick & Wijdicks, 2014). Mydriasis typically is medication induced, especially with the drug Baclofen, a muscle relaxer and antispastic agent that many people with ALS or multiple sclerosis use. When one pupil is dilated, there is potential for the IR camera to do harm to the retina due to lack of constriction. Secondly, with the pupil enlarged, the eye tracker will have difficulty mapping the eye in order for the system to accurately calibrate.

The clinicians must note that none of the above conditions constitutes an exclusionary factor for an eye gaze trial; however, each one should be considered as a potential factor in eye gaze success and user satisfaction. Based on the visual conditions that a user may have, it is critically important to only calibrate the SGD to the user's eyes. Do not calibrate the eye tracker to another person's eyes and expect a user to be able to use the SGD accurately or efficiently. Likewise, monitoring the dwell time is critical to user success and can prevent eye strain (Majaranta, MacKenzie, Aula, & Räihä, 2006). The ideal dwell time for a user is 0.5 seconds or less. The human eye is not meant to dwell on a particular object for longer than a half second; therefore, having a dwell time close to 1 second or higher can actually frustrate the user and make it appear that the user is unable to have success with the eye tracker.

Physical Status

Positioning of the eye-tracking camera and the user is critical to eye gaze success. The eye-tracking camera and SGD should be securely mounted to the user's wheelchair, floor stand, or table top mount. Likewise, the eye tracker and SGD should be positioned directly in front of the user's face at eye level. If the SGD with an eye tracker is positioned too high, the user may experience eyelid fatigue or eye strain from looking up at the SGD screen. Similarly, if the system is too low, it may not always accurately read the angle of the user's eye because part of the pupil may be cut off due to the sharp downward angle.

Each SGD manufacturer and eye-tracking manufacturer will have different specifications for the appropriate distance to keep the eye tracker from the user's eyes (Farnsworth, n.d.). Checking with the manufacturer on the specified distances is highly recommended. An eye tracker will not recognize the user's eye if the system is placed too far away. However, if the SGD is too close to the eyes, the user may only be able to select one portion of the screen. When an eye tracker is appropriately positioned in front of the user, the user should be able to access all four corners of the screen without difficulty.

Language

Each SGD has a variety of language applications, which provide availability to different language representation methods, different symbol sets, and different numbers of locations on the display. This article will not cover language applications or compare the three language representation methods (i.e., alphabet-based methods, single meaning pictures, multiple-meaning Icons; Hill, 2010) but encourage readers to become familiar with the advantages and disadvantages of each method.

However, SLPs should evaluate the user's linguistic abilities and identify the language representation methods that best match the user's capability in order to complete spontaneous novel utterance generation (Hill, 2010). Also, it is important differentiating the user's linguistic abilities from the eye gaze accuracy and proficiency skills. Last language activity monitoring or data logging should be utilized to monitor a user's linguistic and performance gains during treatment. For more details, see Hill (2010) and Hill, Baker, and Romich (2007).

Cognition

Cognition is another determining factor in eye gaze access success. Training a person not only to take in visual stimuli with their eyes but also to make a selection on an AAC system with them can be a difficult skill to learn for those with executive functioning deficits. A user will have a higher satisfaction rate with the SGD if they are able to maximize how language can be represented and generated with any given communication software and to control all the operational features that are available on the SGD with eye tracking. One of the major skills to learn is the ability to pause/unpause the SGD. This allows a user the ability to pause the system, listen to a communication partner, and read an e-mail or view the screen without making selection errors.

SGD Funding Report

Following a thorough AAC evaluation, which should include at least three SGD trials not from the same AAC manufacturer, the SLP or care team will be asked to complete the SGD funding report in order to purchase the AAC device with eye tracking through insurance—private, Medicare, or Medicaid. The most important caveat while writing this intensive report is to remember to always justify the medical necessity of the SGD. This includes justifying the physical, visual, linguistic, pragmatic, and cognitive reasons why the user would benefit from the recommended SGD and eye tracker. The insurance companies will not approve the purchase of an SGD with eye gaze technology if the SGD funding report addresses information related to a user's educational goals or curriculum, vocational or employment goals, or if the SGD funding report states that the user will be able to use the SGD to access a computer for written communication, access the Internet for e-mail, or control electronic devices, such as to play music. The insurance companies expect the SGD to be purchased for face-to-face communication, so it is important to keep in mind the perspective of the medical reviewer. Providing medical necessity caveats specific to the individual enhances your request. This will increase the likelihood that the SGD will be approved for purchase. For more details, see American Speech-Language-Hearing Association (n.d.).

Treatment Plan

Designing a treatment plan for training a person to use an SGD with eye tracking takes planning and coordination with the user's care staff. The treatment plan should address each domain of AAC communicative competence: linguistic competence, strategic competence, operational competence, and social competence (Beukelman & Mirenda, 2013; Light, 1989).

Training the family on how to accurately calibrate and troubleshoot the SGD with eye tracking is essential (Townend et al., 2016). Each eye tracker varies; however, if a user can target each corner of the screen then, generally, an accurate calibration has occurred. Training on no-technology or low-technology methods also is an essential part of a well-rounded treatment plan. Low technology provides a backup system when a high-performance AAC system is not available, inappropriate for the situation or environment, or requires maintenance.

Training a user to use eye gaze as an access method presents some unique challenges. The human eye is only meant to be a receptor in that it takes in visual stimuli for our brain to process an image of our environment. However, with eye gaze, a user is now asked to do three tasks with their eyes: (a) to visually scan a display without making a selection, (b) to take in visual stimuli while adjusting to display changes, and (c) to make a meaningful selection (to generate a message or to perform an operational task). This can be a difficult task and can lead to frustration if a proper treatment plan is not implemented. Once individuals realize that their eyes now have to learn to perform different functions, a treatment plan can be designed to build proficiency while monitoring eye gaze accuracy performance. A second objective that looks at building communication competence using the linguistic features of the recommended software and other social and strategic skills involved with talking with an SGD needs to be designed also. Isolating these two goals of practice using eye gaze access and practice using the language program comes together to measure the overall communication competence of an individual using a high-performance AAC system with eye gaze access.

Conclusion

This article presents the current research evidence related to eye-tracking technologies and eye gaze technique applications with a focus on people with ALS, CP, and Rett syndrome. Several factors and concerns should be considered during the eye gaze technology assessment. Moreover, the article provided clinical guidance for SLPs and other related stakeholders to support professional decision making and practice. Along with this information, clinicians should notice that most individuals who benefit from eye gaze technology have significant disabilities and will require interdisciplinary professional practice. Consequently, interdisciplinary professional education and interdisciplinary professional practice can lay a strong foundation for SLPs considering eye gaze access for a client.

Essential to practice is that SLPs are current with the best external evidence while gathering clinical and personal evidence to measure performance and outcome data during the evaluation, treatment, and daily use. Finally, SLPs should be careful not to over rely on a single manufacturer or a manufacturer's SGD funding template to complete an evaluation. This ensures that individuals and their family are fully informed on all the advantages/disadvantages of available options/products. By building the required knowledge and skills to conduct clinical work independent of manufacturers' marketing, training programs, and sales support, SLPs can feel confident that their clients will successfully operate their AAC and eye gaze devices to maximize their quality of life and communication.

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