JSLHR

Research Article

Visual Attention to Cued Targets in Simulated Aided Augmentative and Alternative Communication Displays for Individuals With Intellectual and Developmental Disabilities

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Purpose: Many aided augmentative and alternative communication (AAC) systems require the use of an external display that is represented via a visual modality. It is critical to evaluate and understand visual–perceptual processing in individuals with disabilities who could benefit from AAC. One way to evaluate how individuals process visual materials is through research-based automated eye-tracking technologies that obtain a fine-grained stream of data concerning gaze paths of visual attention.
Method: The current study examined how individuals with autism spectrum disorder (*n* = 13), Down syndrome (*n* = 13), intellectual and developmental disabilities (*n* = 9), or typical development (*n* = 20) responded to a spoken prompt to find a thumbnail-sized navigation key within a complex AAC display, including a main visual scene display (VSD) and a navigation bar of four thumbnail-sized VSDs. Stimuli were presented on a monitor containing automated eye-tracking research technology that recorded patterns of visual attention.
Results: Participants across groups spent more time fixating on a target thumbnail VSD navigation image after the presentation of the spoken cue to look at the target, compared to before the presentation of the spoken cue; they also spent more time looking at the target thumbnail VSD than the other thumbnail-sized VSDs in the navigation bar after the cue.
Discussion: Participants were able to locate the target thumbnail VSDs, even within the context of a visually complex AAC display. Implications for the design of AAC displays and for assessment of comprehension are discussed.

Eye-tracking research technologies can provide important data on patterns of visual attention of individuals with intellectual and developmental disabilities (IDD; e.g., Venker & Kover, 2015; Wilkinson & Mitchell, 2014). These technologies offer a fine-grained stream of data indicating how participants view or respond to visual stimuli (e.g., how long participants fixate on or look at specific elements, how rapidly participants fixate on any given element). Measurement of eye gaze behavior offers potential insight into the ways that individuals with IDD respond to and process visual information, especially individuals who are unable or unwilling to participate in assessment using traditional methods (Wilkinson & Mitchell, 2014). For instance, gaze behavior has been examined as a means to evaluate comprehension of spoken words by young children with autism spectrum disorder (ASD) who might not provide reliable pointing responses on traditional vocabulary assessment tests. Brady et al. (2014) and Chita-Tegmark et al. (2015) demonstrated the potential for gaze behavior, captured via automated eye-tracking technology, to be used to assess how young children with (or at risk for) ASD respond when given a spoken cue to find a target. Venker and colleagues (Venker, 2017; Venker et al., 2019, 2013) examined gaze behavior as a means to probe for word and sentence processing using either hand coding of gaze behavior from videos or automated technologies. In these studies, response to a spoken cue was indexed by significantly increased gaze to the target after presentation of the spoken cue.

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Editor-in-Chief: Stephen M. Camarata
Editor: Mary Alt
Received July 31, 2020
Revision received November 21, 2020
Accepted February 4, 2021
https://doi.org/10.1044/2021_JSLHR-20-00451

Disclosure: *The authors have declared that no competing interests existed at the time of publication.*

Applications of Eye-Tracking Research Within Augmentative and Alternative Communication

Another application of eye-tracking research is to examine how to optimize the design of augmentative and alternative communication (AAC) systems for individuals with complex communication needs. AAC refers to strategies, technologies, and interventions that enhance communication for individuals whose speech is not meeting the full range of their communication needs (see Beukelman & Light, 2020). Many AAC systems display visual symbols such as letters, line drawings, or photographs on pages within a book (low technology) or on the screen of a tablet or dedicated speech-generating device (high technology).

These systems require the use of an external display that is represented and processed visually. Individuals who use these forms of AAC must be able to visually attend to and extract information from the visual display (Blackstone et al., 2007). The physical composition of the AAC display itself impacts visual attention and performance; the composition of AAC displays must be considered to ensure an appropriate fit with the skills of those who use them (Wilkinson et al., 2012). Displays that are visually confusing or hard to use will be less likely to be adopted than those that match the visual–cognitive processing skills of the individuals who use them (Light et al., 2019). It is therefore critical to evaluate and understand display variables that may impact the visual–perceptual processing of individuals who could benefit from AAC, including those with ASD, Down syndrome (DS), or other IDD.

The studies of eye tracking within AAC that have involved individuals with developmental disabilities have used one of two approaches to determine how visual attention is allocated to the contents of simulated AAC displays. One approach (Liang & Wilkinson, 2018; O'Neill et al., 2019; Wilkinson & Light, 2014) has sought to examine which elements within an AAC display naturally attract attention, when the participant simply views an image, that is, during free viewing. These studies have presented participants with simulated "visual scene displays" (VSDs), which are a type of AAC display that depicts people engaged in meaningful activities within an integrated scene, such as a photograph, with communication messages programmed as "hotspots" on those meaningful elements. The eye tracking revealed that visual attention by individuals with DS, ASD, or intellectual disabilities of other origins (IDD) is strongly drawn by the meaningful elements, even within cluttered or complex scenes (photographs). In particular, visual attention is attracted by human figures (Liang & Wilkinson, 2018; O'Neill et al., 2019; Wilkinson & Light, 2014) and images of shared activities that those human figures are engaged in (such as a book that two children are looking at; O'Neill et al., 2019). Visual attention to background items in these photographs is very limited in each of the groups studied, including those with ASD, even if those background items are brightly colored (e.g., a luminant patch of sunlight, a colorful item) or prominently placed.

The other approach to eye-tracking research has examined the effect of different arrangements of symbols on traditional AAC grids on efficiency of visual search within that display, given a visual and/or an auditory cue (Wilkinson & Madel, 2019; Wilkinson et al., 2014). In this type of research, participants are presented a target sample (a line drawing or a photograph accompanied by a spoken cue). After the target is presented, a traditional grid appears, and the participant's task is to find the line drawing that matches the target sample. This body of research has demonstrated that, for individuals with DS, ASD, or typical development (TD), the arrangement of the symbols on the grid affects the efficiency of visual attention during search within the grid, in particular, the likelihood of the participant fixating on nonrelevant distracters during the process of search.

A recent translational study offered pilot evidence that optimal AAC display design facilitates not just efficient visual attention but also the rate of communication during authentic social interactions by individuals with DS (Wilkinson & Bennett, 2021). Similarly, research with adults with acquired disabilities, including aphasia or traumatic brain injuries, has demonstrated how different features of AAC displays (such as presence or absence of text with symbols on a grid or orientation of a human figure within a scene) influence not just patterns of visual attention, in general, but also the relation between visual attention and outcomes, such as the ability to identify themes or messages contained within the displays (Brown et al., 2019; Thiessen et al., 2016, 2014; Thiessen, Brown, Beukelman, & Hux, 2017; Thiessen, Brown, Beukelman, Hux, & Myers, 2017). This body of research has emphasized that the physical characteristics of AAC displays influence visual behavior as well as communication performance and other outcomes related to AAC use.

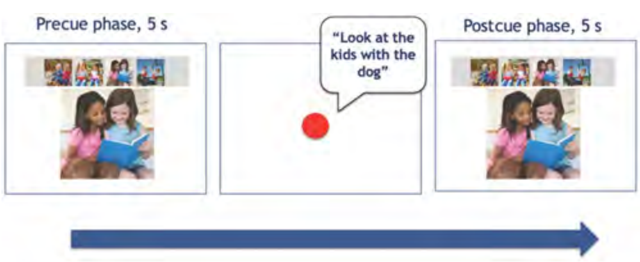
Visual Attention to the Contents of a Navigation Bar on a Complex AAC Display

The current study sought to evaluate visual attention to the contents of a navigation bar on an AAC display, rather than to the contents of the VSD or the traditional grid. Most AAC systems contain more than a single display page. Specifically, on dynamic display AAC technologies, vocabulary is organized across multiple displays in order to provide the individual with access to a large lexicon. Yet, when there are multiple displays, the individual must be able to navigate between the various displays. Navigation between displays may be achieved through a bar that contains hyperlinked navigation keys, which are often miniature versions of the VSDs themselves (Drager et al., 2004). An example of a display that contains a VSD and a navigation bar appears in Figure 1.[1]

The addition of a navigation bar to the main AAC display adds a level of visual and cognitive complexity, as

[1]It is important to note that these were simulated AAC displays shown on a computer monitor; the participants were not required to actually select targets from the display to navigate to another AAC display. We use the term "navigation bar" because the bar was designed to resemble the navigation bar on many AAC apps, but it did not actually function as a tool to support navigation in this study.

Figure 1. An example of one trial viewed by participants, including the initial “precue” 5-s phase, the intertrial screen that presented the spoken cue, and the “postcue” 5-s phase. Note that these images are representative of the kinds of stimuli used across the four bar locations in the study.



the display now contains not just a main VSD (used for communication purposes) but also a navigation bar with multiple small images (to navigate to new displays). In order to navigate successfully between displays, individuals must be able to distinguish the smaller navigation keys not just in isolation (i.e., when presented one by one) but also when they appear as part of an integrated display that includes other navigation keys and the large main VSD. In this instance, when an individual must locate a specific symbol or select a specific symbol to navigate to a new page, it is important to understand the patterns of visual attention that occur when the individual is cued to look at specific elements of the display.

The current study therefore extended prior research by focusing on visual attention to the contents of the navigation bar. Previous studies of visual attention during visual search on AAC displays only included search for content presented within traditional grids, and none of those studies included a navigation bar along with the display (Wilkinson & Madel, 2019; Wilkinson et al., 2014). The studies of visual attention during free viewing similarly focused on visual attention to the contents of the main VSD (Wilkinson & Light, 2014), although one study did have a navigation bar present (O’Neill et al., 2019). Thus far, no studies have examined visual attention during search for content within the navigation bar itself.

Visual Attention in Individuals With Disabilities Who Might Benefit From AAC

Another important aspect of the current study is the inclusion of individuals with communication limitations associated with ASD, DS, or IDD of other origins. It is critical to study individuals with diverse forms of communication disabilities, for both clinical and scholarly reasons. From a clinical standpoint, individuals with limited speech can benefit from AAC regardless of their etiological diagnosis; thus, it is important to understand patterns of visual attention across a wide range of individuals who might use AAC. From a scholarly standpoint, it is critical to understand if or how patterns of visual attention to AAC interact with unique etiological phenotypes. For this reason, it was important to include individuals with diverse etiologies.

Individuals with ASD may present with overselective attention and superior local processing (Dakin & Frith, 2005). For instance, given the particular characteristic of unique circumscribed interests in ASD, it is conceivable that individuals with ASD might show overselective attention to a nontarget item in the VSD, without attending to the target, if one of the nontarget items was especially salient along some preferred dimension (a preferred color, content aligned with a restricted or circumscribed interest). Individuals with DS show a strong proclivity for social interaction, which might be expected to result in increased attention to the large humans within the main VSD, interfering with visual attention to the navigation bar when cued to locate a navigation menu target. Finally, individuals with IDD of other origins often present with selective attention difficulties (e.g., Djuric-Zdravkovic et al., 2010), which would be required to visually attend to the navigation menu during the search for a cued target. Young children with TD were included because research has demonstrated that they often present with similar patterns of visual attention as those with developmental disabilities of similar developmental ages (e.g., O’Neill et al., 2019) and can offer preliminary insights into the developmental contributions to these patterns. Therefore, by including this group, there is the potential to present more robust evidence regarding visual attention to cued navigation targets within complex AAC VSDs that include a navigation bar.

Research Questions

We used a paradigm similar to Brady et al. (2014) and Chita-Tegmark et al. (2015), in which visual attention was measured both before and after provision of a spoken cue. The precue phase provided information on the participants’ viewing of the stimuli before any instructions were given. The data from that first free-viewing phase were analyzed separately to determine how participants allocated attention within the main VSD and were reported in O’Neill et al. (2019). As noted, the current study was the first to examine visual attention to the contents of the navigation bar, rather than the VSD. Specifically, the current study investigated two primary research questions, as well as a secondary question that was afforded due to the structure of the experimental design:

1. Is visual attention to a target miniature VSD within the navigation bar significantly greater after a spoken cue than before it in individuals with DS, ASD, or intellectual disabilities of other origin, as well as in children with TD with similar receptive vocabulary levels? The focus of our research was the visual gaze patterns to the target before and after the spoken cue as a means to understand the different ways in which visual attention was allocated pre- and post-cue. (Note that participants were not cued to touch the target mini VSD because touching would cause occlusion of the eye-tracking data stream.) It was

anticipated that participants would allocate significantly greater visual attention to the target VSD after the spoken cue than before it.

2. Is visual attention to the cued target miniature VSD significantly greater than attention to other miniature VSDs in the navigation bar in individuals with DS, ASD, or intellectual disabilities of other origin, as well as in children with TD with similar receptive vocabulary levels? This second question was necessary to determine whether attention to the items in the navigation bar after provision of the cue was specific/selective to the target (which would be indicated by attention to the target only, postcue) or whether the cue instead resulted in a more general attention to any/all of the items in the navigation bar (which would be indicated by attention to all of the items in the navigation bar, postcue). A real-world navigation task would require scanning through the items within the navigation bar and then dwelling on the target until a selection is made. It was therefore important to evaluate whether attention to the cued target was greater than that dedicated to the nontarget mini VSDs, postcue. It was anticipated that any visual attention after the cue would be specific to the target, that is, that there would be little visual attention to the noncued miniature VSDs; the participants would scan over them without dwelling.

We also addressed a secondary research question that was afforded by the structure of the experimental design: What is the effect of the location of the bar on search within the bar following a cue? One of the questions, which was a primary question in the free viewing study (O'Neill et al., 2019), was whether visual attention within the main VSD during free viewing would be affected by the location of the navigation bar. Therefore, in the 16 simulated AAC displays presented to participants, four had the navigation bar placed on top, four had the bar placed on the bottom, four had the bar placed on the right, and four had the bar placed on the left. Because the structure of the experimental design included this manipulation, we conducted an analysis to determine whether bar location influenced attention to the contents of that bar.

These analyses of the impact of the spoken cue on visual attention have potential implications for the use of eye-tracking research technologies to optimize the design of AAC displays when attention must be focused on specific symbols or elements (as would be the case when navigation is required). Results may also have potential implications for the application of eye-tracking research technologies to assess comprehension.

Method

Participants

Participants included 13 individuals with ASD, 13 individuals with DS, and nine individuals with IDD other than ASD or DS. Participants with ASD were all males aged 10;6–19;5 (years;months). Participants with DS included six males and seven females aged 9;10–23;0. Participants with IDD included five males and four females aged 10;7–28;1. Additionally, data were collected from 20 preschoolers without disabilities (10 males and 10 females) aged 3;2–5;2. Participants were recruited from a charter school in Pennsylvania, a child care center in Pennsylvania, a therapeutic horseback riding program in Massachusetts, and two self-contained schools serving students with severe disabilities in New Jersey and Maryland. Of the 55 participants, 41 (75%) reported that they were Caucasian American, five (9%) reported that they were Asian American, and two (4%) reported that they were African American; an additional three (5%) reported they were Hispanic (one indicated White/Hispanic, the others did not indicate other than Hispanic), and four (7%) did not report their racial or ethnic background. Recruitment occurred via e-mail, in person, and via word of mouth. Ethics approval was obtained from the appropriate agency prior to beginning the study.

All participants met the following inclusion criteria: (a) hearing and vision within normal limits (or corrected within normal limits) per caregiver report and (b) at least 90% accuracy on a prescreening. The prescreening evaluated response to the spoken cues for all four images of each vocabulary concept depicted on the study stimuli. In the screening, participants were presented with a printed page containing four miniature VSDs that were the same size as those they would see during the experimental task. Participants were instructed to select the target image when provided with a spoken cue (e.g., "Point to the kids with the book"). Correct selection on this prescreening also provided an informal functional visual screen to ensure that participants had sufficient vision to discriminate between the small VSDs. However, and importantly, the prescreening differed from the presentation during the experimental task, as the experimental task presented the images within the complex simulated AAC display. Thus, the experimental task probed how well participants responded to the spoken cue within the simulated AAC display for concepts that they had demonstrated that they understood in the simpler prescreening context.

Participants who had developmental disabilities also met the following two additional inclusion criteria: (a) a standard score on the Peabody Picture Vocabulary Test–Fourth Edition (PPVT-4; Dunn & Dunn, 2006) of less than 70 and (b) a diagnosis of developmental disability (i.e., DS, ASD, or IDD of other origin) confirmed by parental and school report. Additionally, in the ASD group, the Childhood Autism Rating Scale (Schopler et al., 1988) was completed by teachers to confirm the presence of behaviors associated with ASD. Childhood Autism Rating Scale scores for participants with ASD exceeded the cutoff of 30, with a mean score of 42 and a range from 30 (mild) to 47 (severe). Table 1 includes summary information for each group including PPVT-4 standard scores, PPVT-4 age equivalent, and chronological ages.

Fourteen additional participants were recruited and tested but did not contribute data to the results. We failed to calibrate nine of the 14 due to strabismus, repetitive

Table 1. Participant characteristics.

Group	PPVT AE		PPVT SS		CA		Screening score		Valid gaze samples (%)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
TD	5.1	1.5	114	14	4.1	0.7	15.9	0.3	67	20
DS	5.6	2.1	44	15	16.5	5.9	15.9	0.3	66	20
ASD	3.5	1.9	30	16	14.6	2.9	15.9	0.3	67	18
IDD	4.8	1.8	40	20	16.9	6.0	16	0.0	62	18

Note. PPVT = Peabody Picture Vocabulary Test; AE = age equivalent; SS = standard score; CA = chronological age; TD = typical development; DS = Down syndrome; ASD = autism spectrum disorder; IDD = intellectual and developmental disabilities.

behaviors (e.g., rocking), and/or lack of attention to the computer screen; these conditions negatively impact calibration. Strabismus is a common ocular condition in individuals with DS and IDD of other origin, and both rocking and lack of compliance are common behavioral issues in individuals with ASD. Of the nine participants who failed to calibrate, five were participants with DS and four were participants with ASD. Five of the 14 additional participants were calibrated successfully and completed the experimental task; however, they were excluded due to lack of valid eye-tracking samples over the study, an inadequate sample to draw reliable conclusions. Tobii Studio software automatically provided the quantity of valid gaze samples for each participant as a weighted gaze samples percentage. This measure was calculated by dividing the number of eye-tracking samples that were correctly identified by the number of attempts and then weighting based on if one or both eyes were detected for each sample. The weighted gaze samples measure was lower when participants looked away from the screen, blinked, or moved (Tobii Pro, 2016). Data were excluded for participants for whom less than 20% of valid eye-tracking samples were obtained over the experiment, as measured by the weighted gaze samples percentage. Lack of valid samples can reflect a variety of issues, including a frank loss of accurate calibration partway through (due to a large, sudden movement like a sneeze) or repetitive behaviors that involve a hand to the eye or head, resulting in occlusion of the eye-tracking data stream. The five participants excluded due to a lack of valid gaze samples included two participants with ASD, two participants with DS, and one participant with TD.

Stimuli

Stimuli were simulated AAC displays that consisted of a main VSD and a navigation bar containing four miniature images of VSDs. Figure 1 depicts an example stimulus. As can be seen in Figure 1, all images contained two children participating in a shared activity. The activities depicted were reading a book (which in Figure 1 is the main VSD and one of the miniature VSDs), swinging on a tire swing, eating lunch, and playing with a dog (these latter three are the remaining miniature VSDs in the navigation bar). The main VSD was centered on the display. The relative sizes of the VSD and the miniature items in the navigation bar reflect general clinical practice in terms of size, as illustrated in Figure 1. The target images in the navigation bar measured approximately 2.5-in. square on the display screen.

Because these populations are challenging to recruit and difficult to test and this investigation used specialized instrumentation that required precise calibration of the orientation of the participants' eyes, data were collected for two separate research studies during a single experimental session. Specifically, participants were presented with 16 trials; one such trial is illustrated in Figure 1. Within each trial, first, there was a 5-s precue phase in which the participant was presented with the simulated AAC display containing a main VSD and a navigation bar with four miniature VSDs, but given no instruction (free viewing). After this precue phase, the presentation automatically advanced to a white screen with a red calibration dot in the center. This screen appeared along with an auditory cue, which instructed the participant to look at one of the miniature VSDs in the navigation bar (not the current main VSD). After this auditory cue, the presentation automatically advanced, and the same AAC display that had appeared in the precue phase appeared again, now in the postcue viewing phase for 5 s.

One of the questions, which was a primary question in the free viewing study (O'Neill et al., 2019), was whether visual attention within the main VSD during free viewing would be affected by the location of the navigation bar. Therefore, in the 16 simulated AAC displays presented to participants, four had the navigation bar placed on top, four had the bar placed on the bottom, four had the bar placed on the right, and four had the bar placed on the left. Within each bar location, there were four photographs that depicted two children engaged in the activity (reading, swinging, snacking, and playing with a dog); thus, for instance, the stimuli depicted in Figure 1 appeared on the four trials where the bar was on the top (though which of the photographs appeared as the main VSD changed on each trial). Different sets of photographs were used across each of the bar locations (top, bottom, left, right). Thus, the photographs used when the bar appeared on the right were also four images of children reading, swinging, snacking, and playing with a dog but were not the same images as those in Figure 1 (and so forth for the bottom and the left bar). The use of different photographs for each bar location served to both introduce some variety to maintain participant interest and reduce confusion that might have occurred if the same photographs appeared in different bar locations.

Eye-Tracking Research Technology

A Tobii T60 research eye tracker[2] was used to record point of eye gaze. A strip at the top of the Tobii monitor projected a safe level of infrared light onto the participants' eyes. This light was reflected off their eyes and recorded by three cameras located in a strip below the monitor. The monitor was connected to a laptop that controlled stimulus presentation and the acquisition of data using Tobii Studio[3] software. The input (samples) from the T60 monitor was recorded as a series of x–y coordinates at a sampling rate of 60 samples per second. A fixation was defined as a sequence of consecutive samples within a 35-pixel area for more than 100 ms, calculated automatically by the software. A threshold of 100 ms was chosen in order to ensure that participants dwelled on the elements of interest and to minimize contamination from blinks, saccades, and other nonfixation behaviors (Manor & Gordon, 2003). This is a common threshold in the literature and has been used in much of the research with individuals with developmental or acquired disabilities (e.g., Brown et al., 2019; Liang & Wilkinson, 2018; O'Neill et al., 2019; Thiessen, Brown, Beukelman, & Hux, 2017; Thiessen, Brown, Beukelman, Hux, & Myers, 2017; Wilkinson & Light, 2014).

Procedure

Sessions occurred in a research laboratory or in a quiet room in the participant's school. First, the researcher administered the prescreening and the PPVT-4. The eye-tracking session began with a calibration phase. The participant sat about 65 cm from the T60 monitor. This distance was automatically calculated by the eye-tracking software. The distance between the monitor and the participant was adjusted as required. A 2-point video calibration was performed, which required the participant to look at a brief video presented in the upper left corner of the monitor followed by the lower right corner. Although it is possible to obtain calibration with greater numbers of points (i.e., either 5 or 9 points), the authors' previous experience with eye-tracking research with individuals with severe disabilities revealed that individuals with developmental disabilities had difficulty with the 5- and 9-point calibration process. Specifically, during 5-point calibration, participants with severe disabilities (particularly those with ASD) tended to look away from the monitor after several calibration points. When prompted to continue to attend to the monitor, participants often used their finger to follow the calibration dot. Both behaviors (looking away and following with a finger) interfered with successful calibration. Because this investigation included fairly large areas of interest (AOIs), the precision of the 2-point calibration was considered sufficient for the purposes of this study.

When the calibration procedure was finished, the quality of the calibration was illustrated in Tobii Studio by green lines of varying length. The length of each line represented the offset between each sampled gaze point and the center of the calibration dot. Points with green lines that extended beyond the edges of the calibration circle or missing points were selected and recalibrated. For participants who were not calibrated due to lack of focus on the calibration points, Tobii Studio indicated "not enough calibration data." Two attempts were made to recalibrate these participants before they were excluded (i.e., the nine participants described in the Participants section). These participants completed the task in "preview mode," and no eye-tracking data were collected. When calibration was repeated and successful, the final calibration with sufficient calibration data was used.

During the precue phase at the start of each trial, the image was presented on the monitor for 5 s; the participant was given no instruction. The presentation then automatically advanced to a white screen with a red calibration dot in the center. This screen appeared, along with an auditory cue, which instructed the participant to look at one of the miniature VSDs in the navigation bar (not the current main VSD; e.g., "Look at the kids at lunch"). The carrier phrase "look at" was chosen in order that (a) there be a clear direction concerning what participants were expected to do and (b) participants would not try to actually reach for or touch the target, which would occlude the eye-tracking apparatus and which might occur with a carrier phrase such as "find the kids…." The four carrier phrases were "Look at the kids at lunch," "Look at the kids on the swing," "Look at the kids with the dog," and "Look at the kids with the book."

After the cue, the presentation automatically advanced, and the same simulated AAC display that had appeared in the precue phase appeared again, now in the postcue viewing phase for 5 s. These same procedures were repeated for each of the 16 stimuli (i.e., AAC displays).

Dependent Measures

Data were collected automatically by the eye-tracking research technology. AOIs were created within each stimulus (i.e., AAC display) using the drawing tool on Tobii Studio software. The drawing tool of the software allowed the researcher to use the mouse cursor to draw boundaries (either with preset shapes, such as squares or rectangles, or freeform) around elements of interest to the study. In this study, AOIs were created for each miniature VSD in the simulated navigation bar. For each trial, the miniature VSD that was cued (e.g., "Look at the kids on the swing") was labeled as the "target" AOI. The other miniature VSDs in the bar were labeled as "others." The AOIs were not visible to the participants during the experimental task.

[2]The Tobii T60 eye tracker is a product of Tobii Pro (https://www.tobiipro.com/)

[3]Tobii Pro Studio is a product of Tobii Pro (https://www.tobiipro.com/)

The dependent measure was the percentage of each participant's own total viewing time that was spent on each AOI within the navigation bar (i.e., each miniature VSD within the bar). Thus, if a participant viewed the entire stimulus for 3 s and the target AOI for 1 s, the percentage would be 33% of their viewing time to the target. It was necessary to calculate the percentage of time spent within the AOI relative to each participant's individual viewing time, rather than the absolute viewing time (i.e., 5 s), because participants fixated for different total amounts of time on each trial. In the TD group, time spent on the whole stimulus ranged from 2.31 to 4.52 s (difference = 2.21 s); in the DS group, time spent on the whole stimulus ranged from 2.42 to 4.62 s (difference = 2.19 s); in the ASD group, time spent on the whole stimulus ranged from 2.77 to 4.5 s (difference = 1.73 s); and in the IDD group, time spent on the whole stimulus ranged from 2.30 to 4.84 s (difference = 2.55 s). Given that time spent viewing the whole stimulus varied, time spent on any individual AOI within it would similarly vary. Thus, a proportion of each participant's own total time spent fixating anywhere was the denominator, and the time spent on the AOIs was the numerator.

Data Analysis

In this study, inferential data analysis was conducted separately for each group of participants rather than conducting comparative analyses across disability groups for several reasons. From a clinical perspective, it is the performance of individuals within each disability group that is of interest rather than the comparison of groups. Furthermore, it is well recognized that cross-group matching can be difficult, given the natural variability across different etiologies (e.g., Charman, 2004; Venker & Kover, 2015) and the substantial age difference for the children with TD (and its associated likely differences in attention, etc.). For instance, individuals with ASD often display an uneven profile, whereby nonverbal cognition often exceeds language skills (Charman, 2004). Individuals with DS demonstrate uneven development across the various domains of language, for example, demonstrating strengths in selective aspects of vocabulary and pragmatics but difficulties with syntax (Abbeduto et al., 2007). Furthermore, excluding participants from a diagnostic group who could not be closely matched with a participant in another group would eliminate those participants with the lowest receptive language scores, who are exactly those who would be the most likely to benefit from these types of AAC supports.

The decision to treat each group separately in analysis was reinforced by the natural variation in the age-equivalent scores of our participants. We compared the age-equivalent scores of the participants, since standard scores for the TD group were within the average range, which was not the case for the participants with IDD. Although mean age-equivalent scores for all participants fell at or below 5;6, analysis of variance indicated that the four groups differed on their age-equivalent scores, $F(3, 49) = 2.96$, $p = .041$. Two-way contrasts indicated that scores for participants with TD, DS, and IDD did not differ from one another: $t(31) = 0.68$, two-tailed $p = .5$ for TD versus DS; $t(26) = 0.431$, two-tailed $p = .67$ for TD versus IDD; $t(19) = 0.81$, $p = .428$ for DS versus IDD. Scores for participants with ASD differed significantly from those with TD, $t(30) = 2.59$, two-tailed $p = .015$, and those with DS, $t(23) = 2.5$, two-tailed $p = .02$, though they did not differ from those with IDD, $t(18) = 1.53$, two-tailed $p = .143$, whose scores were intermediary between ASD and those with DS and TD. This reinforced our decision to treat the groups separately in analysis.

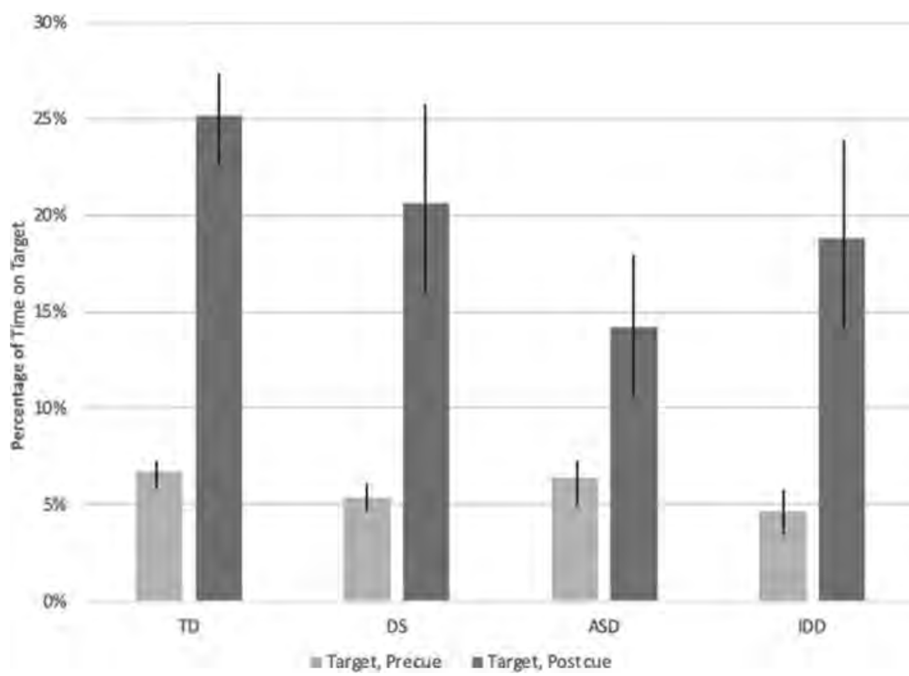
Separate analyses were therefore conducted for each etiological group. For each group, planned contrasts were examined to evaluate the primary research questions: (a) the fixation duration to the target miniature VSD in the navigation bar in the postcue phase relative to its duration in the precue phase and (b) the fixation duration to the target miniature VSD in the postcue phase relative to the other nontarget miniature VSDs in the postcue phase. Testing took the form of one-tailed paired *t* tests between the contrasts of interest (target pre- and postcue; target vs. others, postcue). Within each group, the *p* value was adjusted for the two comparisons, to be $p = .025$ (.05/2). One-tailed tests were used because of the a priori predictions about the direction of change.

Results

Figure 2 presents the results for the first primary research question, concerning the mean percentage of time spent on the target, pre- versus postcue. Although all participant groups are represented on the chart, analyses were conducted separately for each group, for the reasons articulated in the Method section. Table 2 presents the planned a priori analyses that examined the specific contrasts for both research questions, including the value of the *t* statistic and estimated one-tailed *p* value. The paired *t* tests indicated that the percentage of fixation time spent on the target was significantly greater after the cue than before it; results were statistically significant for all groups. Descriptively, all 20 (100%) of the children with TD showed proportionally greater fixation time on the target postcue compared to precue; this pattern was observed for 11 of the 13 participants (84.6%) with DS, 11 of 13 participants (84.6%) with ASD, and eight of nine participants (88.9%) with IDD.

Figure 3 presents the results for the second primary research question, concerning whether visual attention postcue was selective to the target or whether equally high levels of visual attention were also allocated to the other miniature VSDs (the noncued items in the bar), postcue. In Figure 3, the percentage of time spent fixated on three nontarget mini VSDs in the navigation bar was calculated as a mean across the three. The use of an average of the three nontarget mini VSDs in the bar rather than entering each item individually into the analysis (i.e., four contrasts) was done after initial examination of the percentage of time spent on the miniature version of the main VSD (in Figure 1, this is the miniature image of the kids with the book) versus the two other nontarget mini VSDs. As Table 3 illustrates,

Figure 2. Mean percentage of time spent viewing target miniature visual scene display, during precue versus postcue presentation. Note that, although the groups are all presented in this chart, the analyses were conducted separately for each group. Error bars represent standard error of the mean. TD = typical development; DS = Down syndrome; ASD = autism spectrum disorder; IDD = intellectual/developmental disabilities of other origin.



the mean percentage of time (and the standard deviations) spent on each of the three types of nontarget mini VSDs (the miniature of the main VSD and the other two items) was virtually indistinguishable. This allowed us to take an average of the time across the three nontarget mini VSDs and, in turn, simplify the analytic approach. The planned *t* tests (see Table 2) indicated that, after the cue, the percentage of fixation time to the target was significantly greater than fixation to other items in the bar; again, this result was statistically significant for all groups with the *p* value adjusted for multiple comparisons.

Because we had manipulated the location of the bar relative to the VSD for the research question regarding free viewing (O'Neill et al., 2019), a secondary analysis was conducted to determine whether bar location influenced the percentage of fixation to targets, postcue. Bar location had no statistically significant influence on fixations, postcue.

Discussion

This study evaluated the effect of a spoken cue on visual attention to a target within a navigation bar that

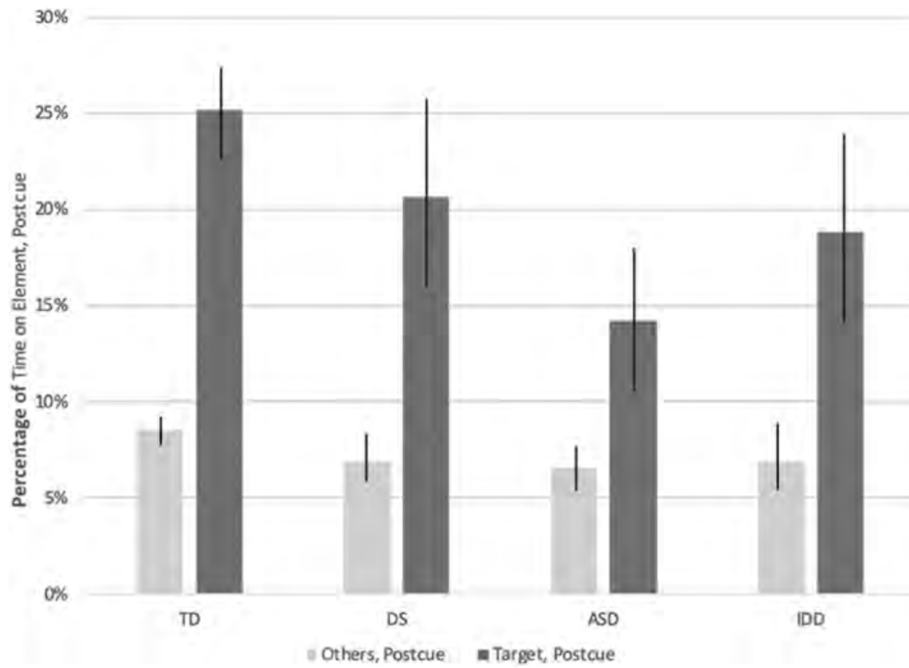
Table 2. Summary results of planned paired one-tailed *t* tests.

Group	Contrast	*t*	*df*	*p*
TD	Target: pre- vs. postcue (RQ1)	7.89	1, 19	< .001*
	Postcue target vs. postcue other items (RQ2)	6.72		< .001*
DS	Target: pre- vs. postcue (RQ1)	3.15	1, 12	.004*
	Postcue target vs. postcue other items (RQ2)	2.79		.008*
ASD	Target: pre- vs. postcue (RQ1)	2.36	1, 12	.018*
	Postcue target vs. postcue other items (RQ2)	2.25		.022*
IDD	Target: pre- vs. postcue (RQ1)	2.79	1, 8	.012*
	Postcue target vs. postcue other items (RQ2)	2.57		.017*

Note. RQ1 indicates that the analysis was conducted for Research Question 1; RQ2 indicates that the analysis was conducted for Research Question 2. All analyses were conducted separately for each group. *df* = degrees of freedom; TD = typical development; DS = Down syndrome; ASD = autism spectrum disorder; IDD = intellectual/developmental disabilities.

*p = .025.

Figure 3. Mean percentage of time spent viewing target miniature visual scene display versus the other items in the bar (mean), postcue presentation. Note that, although the groups are all presented in this chart, the analyses were conducted separately for each group. Error bars represent standard error of the mean. TD = typical development; DS = Down syndrome; ASD = autism spectrum disorder; IDD = intellectual/developmental disabilities of other origin.



simulated some types of navigation bars on actual AAC devices. The aim was to explore visual attention to the content of the bar, specifically, the target miniature VSD by individuals with diverse IDD. The analysis for Research Question 1 indicated that the mean proportion of each participant's fixation time spent on the target in the bar increased substantially after the spoken cue was presented. Moreover, the analysis for Research Question 2 indicated that the mean proportion of each participant's time on the target postcue was significantly greater than the time on the other, nontarget items in the bar, indicating that the effect of the cue was to focus visual attention specifically on the target, without concomitant attention to the nontarget items in the bar. The results provide information regarding how individuals with ASD, DS, and other IDD attend visually to simulated complex AAC displays that include a navigation bar containing navigation keys. Additionally, the results reinforce the potential utility of using eye tracking to measure language comprehension among individuals with developmental disabilities.

Effect of the Cue on Visual Attention Within Complex AAC Displays

Provision of a cue produced robust changes in how long participants fixated on the target miniature VSD within the navigation bar. The percentage of time participants spent fixated on the target after the cue was significantly greater than the percentage of time spent on the target before the cue in all groups. Moreover, the visual attention

Table 3. Percentage of fixation time on distracters and mini visual scene display (VSD) in navigation menu pre- and postcue by group.

	Precue %, *M* (*SD*)			Postcue %, *M* (*SD*)		
Group	**Distracter 1**	**Distracter 2**	**Mini VSD**	**Distracter 1**	**Distracter 2**	**Mini VSD**
TD	8.11 (3.9)	9.39 (4.2)	9.34 (4.7)	8.33 (2.4)	7.87 (3.3)	9.49 (2.5)
DS	5.95 (2.2)	4.27 (2.8)	6.00 (4.7)	7.57 (4.3)	7.02 (2.8)	6.13 (2.5)
ASD	7.24 (3.9)	6.30 (4.3)	6.67 (3.9)	7.34 (5.0)	5.62 (4.2)	6.74 (3.9)
IDD	5.07 (4.9)	6.16 (5.4)	8.68 (7.1)	6.29 (4.2)	6.49 (5.4)	7.89 (5.5)

Note. Paired *t* tests indicated that there were no significant differences between percentage of time on individual items, in any groups (*p* ranges from .07 to .97). TD = typical development; DS = Down syndrome; ASD = autism spectrum disorder; IDD = intellectual/developmental disabilities.

was specific to the target, that is, the presentation of the cue did not result in visual attention to all of the miniature VSDs in the navigation bar, in general, but rather focused the attention specifically to the target miniature VSD. These findings suggest that participants were able to substantially narrow their visual attention in response to the cue despite the relatively complex AAC displays that included numerous potential distracters, including the main VSD and three other miniature VSDs within the navigation bar.

The overall pattern was representative of the majority of individuals within each group. Indeed, only five out of 35 participants with developmental disabilities did not attend to the target for longer after the cue was presented. Informal examination explored whether specific intrinsic factors (e.g., chronological age, PPVT-4 score, PPVT-4 age equivalent) may have influenced performance, and no obvious factors emerged. Future research is needed to examine the potential reasons for this, including the possibility that the added visual complexity of the simulated AAC display may have caused difficulty locating the target, that the use of a point response in the prescreening may have promoted looking that was not required in the gaze task, or that attentional demands or working memory demands might have interfered with the participants' performance in response to the cue to the simulated AAC display.

Implications for AAC Display Design

This investigation provides several important implications regarding the design of AAC displays. Traditionally, dynamic display AAC technologies have not included a navigation bar alongside the main display. Instead, there is usually an entire menu page containing symbols that link to possible AAC displays. When a symbol is chosen, the menu page disappears and is replaced by the AAC display associated with the chosen symbol. Drager et al. (2004) found that this type of menu system posed significant challenges for navigation among 3-year-old children without disabilities, likely due to the cognitive demands of having to recall the other possible displays within the system and understand that the symbols on the menu page are tools to navigate to these alternative displays. Additionally, this type of menu page may impose greater visual cognitive processing demands since the individual symbols must be processed separately. In contrast, young children and individuals with developmental disabilities have demonstrated significant success learning to navigate when the bar is available at all times and includes miniature images of all possible displays (much like the simulated AAC displays used in this investigation; Light et al., 2016). This study suggests that, even with the increased visual complexity introduced by the inclusion of a navigation bar with four miniature VSDs, participants attended to the cued miniature VSD within the navigation bar following presentation of the spoken cue. Therefore, an omnipresent navigation bar may offer benefits.

The structure of the experimental design also allowed us to explore a secondary question about the effect of navigation bar location on visual attention after the spoken cue. O'Neill et al. (2019) had found that the location of the navigation bar influenced visual attention to content within the main VSD during the free viewing, insofar as participants fixated for longer on meaningful elements within the main VSD when the bar was proximal to that element. Bar location did not exert an influence on the duration of fixation to the cued target within the navigation bar after the cue was presented. This suggests that, once prompted to find a target that was within the bar itself, participants were able to do so irrespective of where the bar appeared relative to the VSD.

Implications for Assessment

The results of this study add to previous studies that have suggested that eye tracking may be a valuable means to gain information about how young children and individuals with IDD respond to a spoken cue, especially individuals who are unable or unwilling to comply with traditional assessment tasks that require some form of motor response (e.g., Brady et al., 2014; Chita-Tegmark et al., 2015). However, the current study extended the prior studies in particular in two ways: the stimuli used and the populations sampled. First, in the prior studies, participants were presented with four fairly simple line drawing stimuli (Brady et al., 2014) or two large photographs at a time (Chita-Tegmark et al., 2015). In contrast, the current study examined response to a spoken cue when the stimuli were more complex, with a main VSD and four miniature VSDs within a simulated navigation bar. Second, the current study extended the etiologies of interest beyond individuals with ASD to those with DS and those with IDD of other origin.

Although the prior research has suggested the potential of eye-tracking technologies to investigate responses to spoken cues as measures of language comprehension, it is of critical importance to determine what measures are most appropriate for capturing changes that are clinically significant. Measures of frequency, duration, or latency of visual fixation have all proven difficult to interpret at times as the relative amount of change needed to be considered a "significant" change is unclear. The measures used in the current study—specifically the contrast between the percentages of individual viewing time spent on the target in the precue versus the postcue condition—may provide a useful clinical tool. Clearly, future research is required to validate this approach and to explore other measures that can be used for those individuals who are either unable or unwilling to participate in traditional behavioral assessment tasks. Such tools will play a valuable role in advancing understanding and improving intervention for this population, which is currently not well served.

Although eye-tracking research technologies provided an effective, alternative means to investigate the response to a spoken cue in the majority of the participants in the current study, it is important to recognize that there remained a small number of participants with ASD (n = 2), DS (n = 2), and IDD (n = 1) who did not demonstrate the expected change in visual attention despite their previously demonstrated understanding of the spoken cues (as demonstrated by their pointing responses in the prescreening task). Future research is required to explore alternative assessment techniques and to determine which individuals may benefit most from which approaches.

Limitations and Future Research

This study included a small number of participants within each group, and representation of racial and ethnic minorities was somewhat limited. Given the diversity within and across the clinical groups studied, these data must be considered a first step. Furthermore, 29% of the participants recruited were not included in the data analysis, either because they could not be calibrated or because there were insufficient valid eye-tracking samples. It is not known how the patterns of visual attention of the participants who were excluded compared to those who were included in the data analysis. It is important to note that the lack of success at calibration in this research setting, which occurred in a single research session, does not reflect on the potential use or success of clinical eye-tracking access methods for these individuals. When considering eye-tracking technologies for clinical purposes, different types of technologies are trialed, ideally over a period of time, in order to find the best fit for each individual. In our research, by contrast (and of necessity), the research session was a single session with a single type of research-based technology.

In addition, the experimental task was completed in a lab environment that was unlike an actual communication exchange in which these AAC displays would be used. The navigation target was prompted by the experimental setup, and moreover, the display disappeared between trials, both of which differ from typical clinical experiences. It is necessary to begin to examine whether the visual attention patterns observed in this study would be similar when an individual is spontaneously searching an actual navigation bar in a more naturalistic setting and during a social interaction. For instance, self-generated navigation might promote motivation and attention to the targets, even further than we observed here. Examination of visual attention during more naturalistic opportunities is clearly warranted.

Participants completed the experimental task only one time; it is necessary to study directly how visual attention patterns change over time with repeated exposure to the displays. Additionally, the spoken cue to look at an item within the bar was presented before the presentation of the display, posing some demands on working memory that may have impacted performance. Moreover, the display did not change when participants looked at the cued target, which may have also impacted performance. In addition, the cued phase of this study was interspersed with the precued viewing phase, and it is unknown how the integration of the two phases may have impacted attention and performance.

The limitations of this study raise several directions for future research. First, future research should extend beyond the lab setting to evaluate performance in actual communication exchanges. A study is currently underway that uses mobile eye-tracking glasses to evaluate visual attention during an actual navigation task, in which participants select target miniature VSDs with the navigation menu (Barwise et al., 2019). Second, future research should include larger numbers of participants to enhance the generality of the findings. Finally, research should investigate patterns of visual attention over time, as individuals have repeated exposure to the displays.

Conclusions

Individuals with significant developmental disabilities and complex communication needs must be provided with AAC displays that align with their underlying visual–cognitive processing skills. In order to design AAC displays that are grounded in a solid understanding of visual–cognitive processing, investigations of visual attention to these displays are critical. In this study, individuals with ASD, DS, and other IDD were able to narrow their attention and attend visually to the targets in response to the spoken cue within the context of visually complex AAC displays. Future research should continue to evaluate various aspects of AAC system design in order to ensure a good fit between the needs and skills of individuals and the design of the displays.

Acknowledgments

This research was supported by National Institute on Disability and Rehabilitation Research Grant 90RE5017 of the Department of Health and Human Services; the Rehabilitation Engineering Research Center on Augmentative and Alternative Communication (AAC-RERC) and U.S. Department of Education Grant H325D110008, through the Penn State Augmentative and Alternative Communication Project, all awarded to Janice Light. Thanks to the Midland School, the Ivymount School, Greenlock Therapeutic Riding Center, and the Hort Woods Center for supporting this research.

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