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Research Note

# Eye Tracking Measures Reveal How Changes in the Design of Displays for Augmentative and Alternative Communication Influence Visual Search in Individuals With Down Syndrome or Autism Spectrum Disorder

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**Purpose:** This research note reports on how small changes to the organization of a simulated display for augmentative and alternative communication influence the visual search patterns of individuals with Down syndrome or autism, as measured through eye tracking technologies. Prior research had demonstrated that clustering symbols by their internal color facilitates search and reduces attention to distracters, in children with typical development. This research systematically replicated the procedures with individuals with Down syndrome or autism spectrum disorder.

**Method:** Participants engaged in a visual search task on a monitor with embedded automated eye tracking technology. Patterns of gaze during search were measured via this technology.

**Results:** Participants were significantly faster to fixate on the target and to select it with the mouse when the like-colored symbols were clustered together. In addition, participants were significantly less likely to fixate on distracters in the clustered condition. No group differences were found.

**Conclusions:** Small changes to the organization of the simulated augmentative and alternative communication display resulted in substantial differences in eye gaze and speed to find a target. Of greatest clinical import is the finding that clustering symbols reduced attention to distracters, given that individuals with disabilities may be prone to distraction.

Augmentative and alternative communication (AAC) refers to a wide variety of technologies and intervention approaches aimed at promoting communication in individuals for whom speech does not meet all of their communication needs. AAC can also include both aided high-technology speech-generating devices and low-technology communication booklets, as well as unaided gestures, sign language, or other nonspeech forms of communication. AAC has been demonstrated to be effective in a wide range of individuals, including those with developmental disabilities (autism spectrum disorder [ASD], Down syndrome [DS], Angelman syndrome) and individuals with acquired disorders (amyotrophic lateral sclerosis, traumatic brain injury [TBI]; see Beukelman & Mirenda, 2013).

As Wilkinson and Hennig (2009) reviewed, AAC that relies on either high- or low-technology typically involves a visual modality to display and access vocabulary, rather than the aural/oral (sound/speech) modality of spoken language. The use of such a visual modality for communication places a unique set of demands on the user, as vocabulary must be stored and accessed from an external device, and message preparation can oftentimes be quite slow. However, a variety of strategies can contribute to maximizing the success of AAC interventions, including selection of appropriate vocabulary, training of communication partners, and various word prediction strategies (Johnson, Inglebret,

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Jones, & Ray, 2006; Kent-Walsh, Binger, & Hasham, 2010; Kent-Walsh & McNaughton, 2005).

In 2004, Wilkinson and Jagaroo proposed that the match between the physical design/layout of the AAC displays and the visual cognitive skills of their users might be another consideration in the success of AAC interventions. They argued that if the display is confusing or hard to use, the user might be more likely to abandon their AAC in favor of other (less conventional) communication methods. Extrapolating from the visual cognitive neurosciences, Wilkinson and Jagaroo outlined several visual perceptual features that influence visual cognitive processing that might be relevant to optimizing the design of visual AAC communication displays, including symbol internal color, symbol spatial arrangement, symmetry of the symbol shape, and axial orientation.

**Studies of Design Features (Other Than Those in the Current Study)**

Since Wilkinson and Jagaroo's initial argument, researchers have examined the influence of various visual perceptual features on visual attention, across a variety of populations. In some cases, the studies were directly seeking to contribute to the body of knowledge concerning AAC display design. For instance, Wilkinson and Light (2011, 2014) examined whether human figures would attract visual attention within photographs even if they were small or offset, in an effort to inform design of visual scene displays for AAC. They found that humans were preferentially attended, no matter where they appeared or what other items appeared with them, across participants with typical development, ASD, DS, or intellectual disabilities of other origins. Brown, Thiessen, Beukelman, & Hux, 2015 examined the influence of using text-only, icon-only, or text-plus-icon symbols on the speed of locating a target by individuals with TBI, and found that icon only (with no text) led to most efficient visual search. Thiessen, Brown, Buekelman, Hux, and Myers (2017) examined image/symbol type (isolated icon, decontextualized photograph, or contextualized photograph) on visual attention by individuals with TBI in response to message prompts that involved a "naming" message ("Which of these would you choose if you wanted to say 'teapot'?") versus ones that involved action messages ("Which of these would you choose if you wanted to tell me about making a hot drink?", p. 432); the type selected depended, in part, on the message type.

In other research on attention, more generally, but that is relevant to AAC, Thiessen et al. examined how the gaze direction of a person within a photograph influenced visual attention of participants viewing that photograph, in individuals with aphasia (Thiessen, Beukelman, Ullman, & Longenecker, 2014) or TBI (Thiessen, Brown, Beukelman, & Hux, 2017), and Fletcher-Watson, Findlay, Leekam, and Benson (2008) examined similar questions in individuals with ASD. Although individuals with aphasia and TBI showed greater attention to an item being scrutinized by a person in a photograph (Thiessen et al., 2014; Thiessen, Brown, Buekelman, & Hux, 2017), this did not appear to be the case with individuals with ASD (Fletcher-Watson et al., 2008). All of these studies, however, demonstrated the importance of examining the design of AAC displays on patterns of attention and responding by individuals who might use them.

**Studies of Symbol Internal Color and Spatial Organization**

Relevant to the current study, a series of initial proof-of-concept studies examined whether simple changes to display design might influence performance on visual search tasks. Visual search was used for the method because dependent measures of accuracy and speed of symbol selection are both critical components of successful AAC. Thus, although the tasks were laboratory-based, the measures under study were relevant to the kinds of performance/skills AAC seeks to support. The symbols used for study were from the Boardmaker Picture Communication Systems dictionary (Mayer-Johnson, 1992), one of the most widespread symbol sets used in clinical practice.

In the first study (Wilkinson, Carlin, & Thistle, 2008), preschool children without disabilities and older individuals with DS underwent the visual search task. Three sets of 12 stimuli each were constructed. One set contained 12 symbols for foods, one set contained 12 symbols for clothing, and the final set contained 12 symbols for leisure activities. Within each set were subsets of four symbols that shared internal color; for instance, in the food set, four of the foods were red (e.g., tomato, cherry), four were green (peas, grapes), and four were yellow (banana, lemon); in the clothing set, there were four red items, four blue items, and four yellow items; and in the leisure activity set, there were four symbols with largely blue coloration (which were water-related sports such as swimming and kayaking), four symbols with largely green coloration (which were outdoor activities like mowing grass, playing soccer), and four symbols with largely yellow coloration (which were vehicle-related, such as motorcycling and car racing).

Once the sets were constructed, two versions of each display were created. In one version, the symbols that shared color (i.e., all the red foods) were clustered together within the array, such that there were three clusters of like-colored symbols on each array. In the other version, the symbols were shuffled or distributed all across the display. Participants were provided with a target sample, and asked to use a mouse to click on/select the matching target from the array. In the food array condition, the target sample was a spoken word, whereas in the clothing array conditions, the target sample was the identical line drawing.

For all three stimulus sets, response time to locate the target symbol was significantly faster for younger preschoolers and individuals with DS when the symbols were clustered by their internal color, suggesting that symbol arrangement by symbol color fostered speed to locate the target. In addition, accuracy to find the symbol was significantly improved under clustered arrangement for younger preschoolers and for those individuals with DS with lower vocabulary scores (accuracy was at fairly high levels under both conditions for older preschoolers and individuals with DS with higher vocabulary scores). This pattern was true irrespective of the stimulus type and complexity (simple foods or clothing vs. the more complex activity items) as well as the target type (spoken word vs. identical line drawing), suggesting that the visual perceptual processes were fairly fundamental and not influenced by those factors.

A further study (Wilkinson & McIlvane, 2013) extended this work by replicating the study with 12 individuals with DS and adding a sample of 12 individuals with ASD. Because the previous study had indicated the effect of clustering held irrespective of stimulus set (food, clothes, activities) or target type (spoken word vs. line drawing), this study used the clothing items but increased the display size to 16, such that there were four red clothing symbols, four blue ones, four yellow ones, and four brown ones. As before, speed of locating the target was significantly faster under clustered conditions for both groups, and accuracy was higher as well, though the effect fell just short of statistical significance ($p$ = .06). Consistent with other indications in the literature, the participants with ASD were significantly faster and more accurate in this simple search task than their counterparts with DS (e.g., Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009).

#### Exploring the Mechanism Underlying Superior Search With Clustered Displays

Although the previous studies revealed that clustered displays result in faster responses and, in some cases, more accurate selections, these studies could not reveal why clustering by internal color might benefit visual search. Automated eye tracking technologies can be used to examine the actual processes of visual attention during visual search to begin to explore these mechanisms. These eye tracking technologies can record the point of gaze during search using infrared light reflected from the participant's eyes during search (see Wilkinson & Mitchell, 2014, for a description of eye tracking technologies as related to AAC research; Karatekin, 2007, for a broader description of the technologies; and Venker & Kover, 2015, for considerations in applying technologies with individuals with neurodevelopmental disorders). Through this technology, underlying differences in the actual search behavior can be recorded to determine how search is affected by the different arrangements.

Wilkinson, O'Neill, and McIlvane (2014) enrolled 14 children with typical development between the ages of 7 and 12 years, and presented them with the same 16-symbol clothing arrays used in Wilkinson and McIlvane's (2013) study. Accuracy was quite high across both conditions, which is unsurprising given that these were older children for whom the task was quite easy. However, once again, the response latency to select the target with the mouse was slower in the distributed condition, and this slower response latency to the mouse click corresponded to a similarly slower latency to fixate on the target. Of greater interest, perhaps, was the pattern of fixations during search. Specifically, in the less efficient distributed condition, participants made significantly greater numbers of fixations to irrelevant distracters, that is, to items that were not the target and that did not share internal color with the target (i.e., if the target was something red, then irrelevant distracters would be the blue, yellow, and brown items). These findings suggested that the inefficient responding in the distributed condition is associated with less efficiency in locating of the target with the eyes and, more importantly, that the clustering of symbols facilitated search by narrowing attention away from irrelevant distracters and toward symbols sharing a relevant feature, in this case, internal color.

#### Research Aims and Questions

The current study was a systematic replication of Wilkinson et al. (2014), in which we examined eye gaze patterns in individuals with either DS or ASD. A direct systematic replication was necessary because the participants in the study by Wilkinson et al. (2014) were children without disabilities between the ages of 7 and 12 years. Developmentally, their language and cognitive levels would be higher than might be expected in individuals with communication and intellectual/developmental disabilities associated with DS or ASD. Patterns of visual search might not be expected to be uniform across developmental levels and/or etiological category. Thus, although the study by Wilkinson et al. (2014) demonstrated the utility of eye tracking to reveal mechanisms underlying performance, it is critical to evaluate whether the same patterns of underlying mechanisms would be seen in individuals with developmental disabilities, who are at earlier developmental language levels.

Our research questions asked how the spatial arrangement of symbols by internal color on a grid display affected the users' efficiency in visual search (measured through eye gaze) and in selecting the target (measured through mouse click). On the basis of the research by Wilkinson and McIlvane (2013), which included individuals with the same diagnoses examined here, we anticipated that participants would be more efficient in selecting symbols (measured via mouse click) when they were clustered by color than when they were distributed across the display. Extrapolating from the findings with children with typical development reported in Wilkinson et al. (2014), we expected that latency to fixate would be faster in clustered conditions, and that there would be significantly more fixations to distracters in the distributed condition.

## Method

### *Participants*

Participants were six individuals with DS and six individuals with ASD (the small sample size is considered in the Results and the Discussion sections). Table 1 provides information about each participant. There were three male and three female participants with DS, who ranged in age from 16 to 20 years at the age of testing ($M$ = 19;3 [years; months]). All participants with ASD were male. These participants ranged from 12 to 17 years old at the time of testing ($M$ = 16;11). All participants with ASD attended a specialized school for individuals with this diagnosis; in addition,

**Table 1.** Participant characteristics.

| Group | Gender | PPVT-4 AE | PPVT-4 AE (months) | Age (years;months) | Age (months) | CARS |
|---|---|---|---|---|---|---|
| Down syndrome | F | 7;2 | 86 | 19;1 | 229 | — |
| | F | 8;2 | 98 | 20;6 | 246 | — |
| | F | 9;1 | 109 | 21;0 | 252 | — |
| | M | 3;5 | 41 | 19;10 | 238 | — |
| | M | 3;0 | 36 | 16;8 | 200 | — |
| | M | 5;11 | 71 | 18;3 | 219 | — |
| Autism spectrum disorder | M | 3;10 | 46 | 19;0 | 228 | 41.5 |
| | M | 3;7 | 43 | 12;7 | 151 | 41.5 |
| | M | 5;3 | 63 | 19;4 | 232 | 30.5 |
| | M | 5;1 | 61 | 17;3 | 207 | 30.5 |
| | M | 5;1 | 68 | 14;8 | 176 | 31 |
| | M | N/A | N/A | 16;2 | 194 | 28 |

*Note.* Scores on the Childhood Autism Rating Scale (CARS) are as follows: 41.5 = severe symptoms of autism; 30.5 and 31 = mild–moderate symptoms of autism; 28 = minimal symptoms of autism. Note that this last score is just 1 point below the cutoff for mild/moderate. N/A means that the participant was noncompliant for the testing of the Peabody Picture Vocabulary Test—Fourth Edition (PPVT-4). AE = age equivalent; em dashes = not conducted.

teachers at the school were asked to fill out the Childhood Autism Rating Scale (Schopler, Reichler, & Renner, 1988). All participants but one had scores ranging from 30.5 to 41.5 (mild/moderate to severe symptoms of ASD); one participant scored 28, which was 1 point below the cutoff for mild/moderate symptoms of ASD. Each participant underwent the Peabody Picture Vocabulary Test–Fourth Edition (PPVT-4; Dunn & Dunn, 2006) before participating in the study. All participants had significant receptive vocabulary limitations as indexed by this measure.

### *Stimuli and Experimental Conditions*

As a systematic replication of prior work, the symbol displays and tasks used here were identical to those used in Wilkinson and McIlvane (2013) and Wilkinson et al. (2014). There were 16 items from the Mayer-Johnson Boardmaker symbol set (Picture Communication Symbols; Mayer-Johnson, 1992). The stimuli consisted of items worn on the feet, four items worn on the torso, four summertime items, and four inclement weather items. Each set of four items shared internal color; the shoes were brown, shirts were blue, summertime items were red, and inclement weather items were yellow.

The 16 stimulus items were arranged into two different displays, as seen in Figure 1: clustered together or distributed by color across the display. Two blocks of 16 trials were generated. Within each block, the trials were all of the same kind, that is, there was one block of 16 clustered trials and one block of 16 distributed trials (total = 32 trials). Within each block, the stimulus items remained in the same location for each condition. In order to minimize possible interference, eight of the 16 targets served as targets for the clustered condition whereas a different eight served as targets in the distributed condition. Order of presentation of the two blocks was randomized across participants to minimize order effects.

**Table 2.** Means and medians for number of fixations to each stimulus type, under each display condition.

| Dx | Stimulus type | *M* CLUS | *M* DIST | *M* CLUS | *M* DIST |
|---|---|---|---|---|---|
| ASD | Target | 25.8 | 32.5 | 26 | 28.5 |
| | Shared color | 26.7 | 19.8 | 24 | 20 |
| | Distracters | 22 | 46 | 16.5 | 43 |
| DS | Target | 34.3 | 33.7 | 34 | 30.5 |
| | Shared color | 30.8 | 29.2 | 26.5 | 30 |
| | Distracters | 15.7 | 48.4 | 14 | 46 |

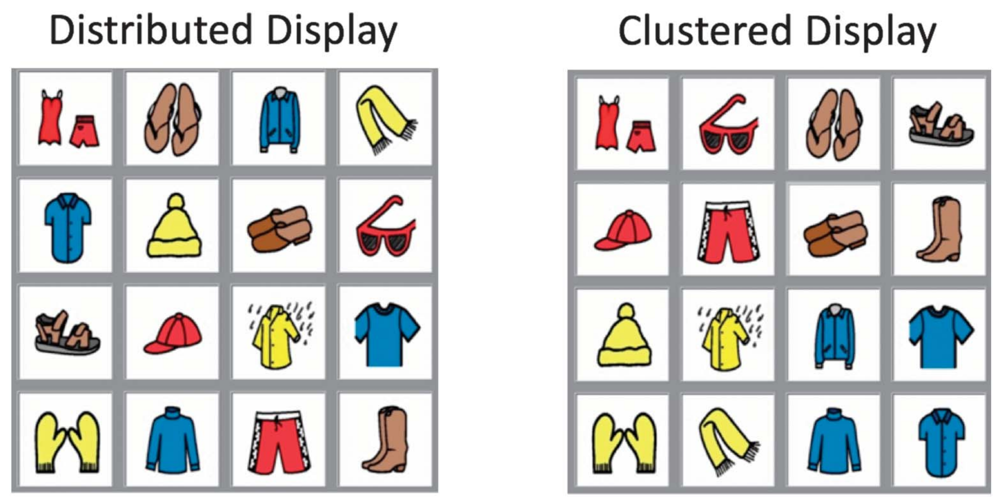
*Note.* Dx = diagnostic status; CLUS = clustered condition; DIST = distributed condition; ASD = autism spectrum disorder; DS = Down syndrome.

### *Research Setting and Task*

Participants worked on a computer placed in a quiet laboratory or in a quiet room at their school. A trained research assistant launched the program that presented the stimuli and acquired the data. The participants were asked to respond via mouse click to the stimuli displayed on the computer screen. Several of the participants with ASD had behavior plans and earned stars or points during the testing session. Participants first underwent one condition (either clustered or distributed), followed by a break and the other condition. The order of presentation of the conditions was randomized as to which condition participants experienced first, clustered or distributed.

At the start of each trial, a sample appeared in the middle of the screen to indicate the target stimulus. The sample was one of the 16 line drawing symbols from the 16-symbol array. After the participant clicked on the sample item, it disappeared and the 16-symbol display appeared. The participant's task was to locate and click on the stimulus in the display that was identical to the sample. For example, if the

**Figure 1.** Conditions used.




red shorts appeared as the sample on the first screen, the target stimulus was the red shorts in the 16-symbol display. No auditory input was provided to the participant. Each session consisted of 16 trials with a 1-s interval between trials.

Prior to starting, the experimenter instructed each participant saying, "First, you are going to see a single line drawing in the middle of the screen. When you click on that with the mouse, it will disappear and you will see 16 other line drawings. Your task is to find the exact same line drawling that you had just seen." During the experiment, the computer software recorded participants' mouse click reaction time to select the target and the patterns of participants' eye gaze fixations during the search task.

### *Recording of Eye Gaze Patterns*

At the beginning of each session, the participant was calibrated to the Tobii T60 eye tracker. The participant sat at approximately 65 cm away from the 17-in. Tobii monitor and was instructed to look at a brief video that appeared first in the upper left corner of the screen and then in the lower right corner of the screen. A 2-point calibration was used because the researchers' experience with eye tracking with individuals with severe disabilities indicated that many have difficulty sustaining attention for the duration of the larger calibration arrays (5 or 9 points). The lower calibration display was considered adequate for this study because the stimuli in the current study were fairly large (we were not looking at small stimuli such as print). During this period, the Tobii monitor calibrated the location of participant's gaze based on the participant's distance from the screen, the location of the pupil, and the curvature of the eyeball. From this information, the location of gaze could be calculated automatically by the software. Small head movements were accommodated by a remote camera during data collection. A personal computer was connected to the Tobii T60 eye tracker and used to collect data and control the presentation of the stimuli.

### *Dependent Measures*

Dependent measures included (a) overall accuracy in selection; (b) mean and median latency to fixate on target item; (c) mean and median latency to click on target item; and (d) the number of fixations to the target item, the three like-colored items, and the 12 irrelevant distracters. The independent variables were condition (clustered vs. distributed) and group (DS vs. ASD). Presentation of both mean and median latencies in chart or tabular form allowed evaluation of the impact of outlier trials, and was conducted in this case due to the smaller sample sizes.

### *Data Analysis*

Although the sample sizes were small, the data were analyzed using parametric analysis because of the within-subject nature of the condition (clustered vs. distributed) independent variable. The data were evaluated for violation of assumptions for parametric analysis, and none were found. Thus, mixed $2 \times 2$ analysis of variance (ANOVA) evaluated the effects of condition (within subjects) and group (between subjects) on the dependent measures. The $p$ value was set at .05, and adjusted for multiple comparisons where necessary.

## Results

Accuracy was quite high for participants in both groups, under both conditions. Mean accuracy for participants with ASD was 94% and 97% in clustered and distributed conditions, respectively (median of 94% and 100%, respectively). Mean accuracy for participants with DS was 94% and 89% in clustered and distributed conditions, respectively (median 94% and 91%, respectively). These high accuracies indicated that participants understood the task at hand. Mixed 2 × 2 ANOVA confirmed that there were no differences in accuracy by condition or across the two groups.

### *Latency to Fixate and Latency to Click on Target*

The mean (filled bars) and median (hash mark bars) of the participants' latencies to fixate on the target are presented in Figure 2. Mixed 2 × 2 ANOVA indicated that the time taken to fixate on the target was significantly longer in the distributed condition than in the clustered condition, with a moderate to large effect, $F(1,10) = 7.17$, $p = .023$, $\eta_p^2 = .417$. There was no difference between the groups nor any interaction between group and condition. We calculated how much faster fixation to target was in clustered displays. For participants with ASD, search was 24% faster (using median) under clustered than distributed displays; for those with DS, search was 23% faster, indicating substantial reduction in latency for the clustered display.

The mean and median of the participants' latency to click on the target is presented in Figure 3. Mixed 2 × 2 ANOVA indicated that time to click on the target was significantly longer in the distributed condition than in the clustered condition, with a large effect, $F(1,10) = 10.96$, $p = .008$, $\eta_p^2 = .523$. There was no group difference nor an interaction between group and condition. We calculated how much faster selection of the target was in clustered displays. For participants with ASD, search was 32% faster under clustered than distributed displays; for those with DS, search was 6% faster (though, their responses were slower to begin with).

### *Number of Fixations to Target, Like-Color, and Irrelevant Distracters*

The mean number of fixations to either the target item (a yellow hat, when presented with the sample of a yellow hat), the like-colored items (the yellow scarf, mittens, or raincoat, when presented with the sample of a yellow hat), or the irrelevant distracters (the brown, blue, or red items, when presented with the sample of a yellow hat) is illustrated in Figure 4. Table 2 presents both the mean and the median numbers as well. Mixed 2 × 2 ANOVAs were conducted to evaluate whether display condition affected the number of fixations to each stimulus type; thus, three ANOVAs were conducted. To adjust for multiple comparisons, Bonferroni correction was made to the $p$ value, resulting in an adjusted $p$ value of .017 (.05/3). There were no significant group or condition effects in the number of fixations directed to either the target stimulus or to the like-colored items. However, a very large effect was found for condition on the number of fixations directed to the irrelevant distracters, $F(1,10) = 23.87$, $p = .001$, $\eta_p^2 = .705$. Individuals with ASD fixated on distracters an average of 2.5 times more in the distributed condition than in the clustered condition, and individuals with DS fixated on distracters almost four times more (3.99) in the distributed condition. There was no

**Figure 2.** Mean and median latency to fixate on target stimulus in each group. ASD = autism spectrum disorder; DS = Down syndrome.

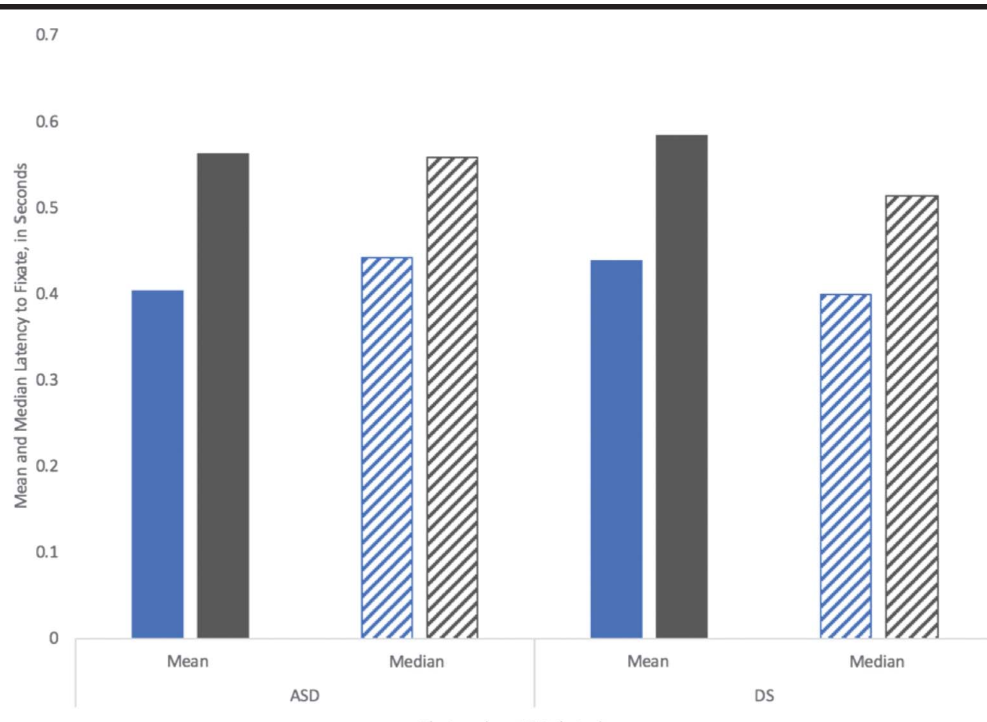


Figure 3. Mean and median latency to click on target stimulus in each group. ASD = autism spectrum disorder; DS = Down syndrome.

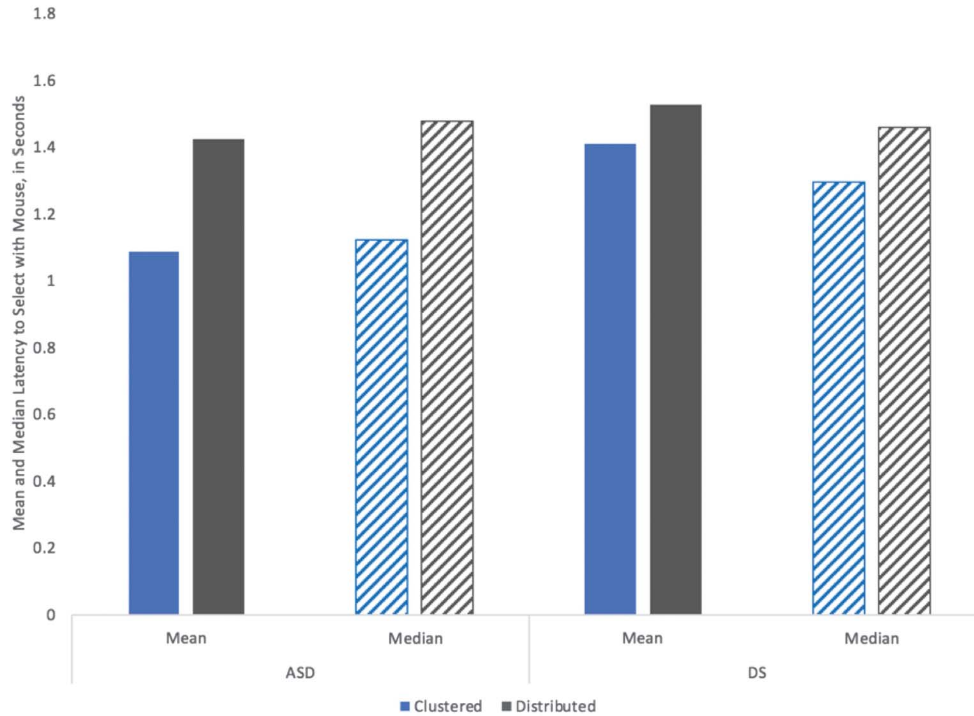
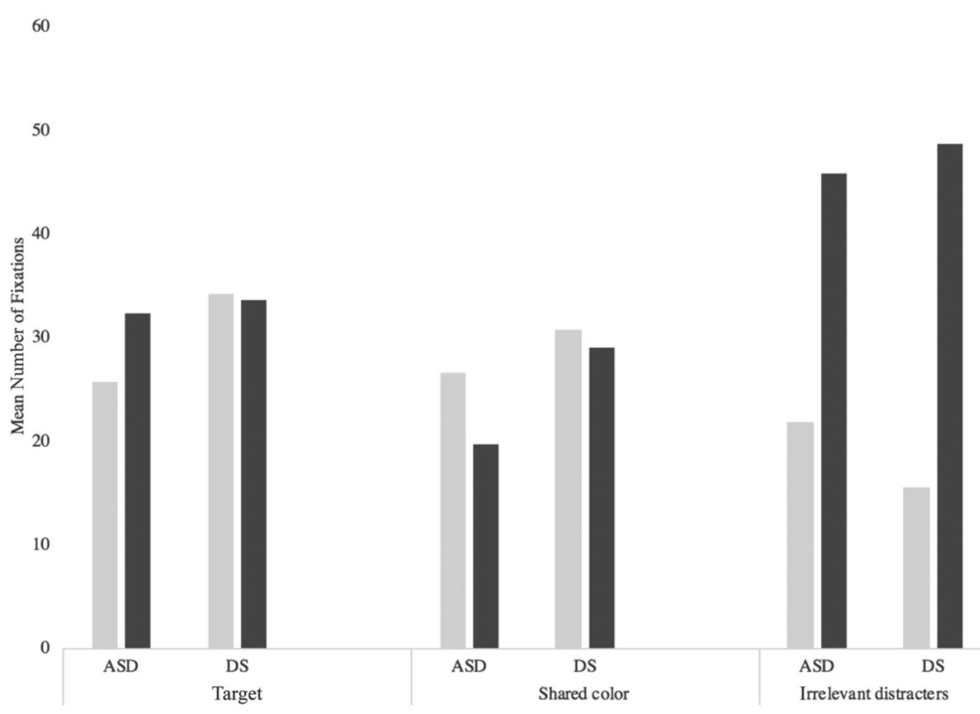



Figure 4. Mean total fixations to each area of interest (target, like-colored items, irrelevant distracters). ASD = autism spectrum disorder; DS = Down syndrome.



difference between the groups nor an interaction between group and condition.

## Discussion

Message preparation in aided AAC can be exasperatingly slow, with cascading negative consequences for various aspects of interaction (e.g., Bedrosian, Hoag, & McCoy, 2003; Hoag, Bedrosian, McCoy, & Johnson, 2004; Light, Binger, & Kelford Smith, 1994; see Beukelman & Mirenda, 2013). The current research indicates that small changes to the arrangements of symbols on an AAC display resulted in immediate and statistically significant differences in both efficiency of visual search as well as speed of clicking on a target in individuals with DS as well as those with ASD. Participants with ASD and those with DS were faster to locate the target via fixation, as well as to click on it with the mouse, when the symbols were clustered by their symbol internal color. Equally if not more importantly, clustering symbols by internal color resulted in significantly fewer fixations to irrelevant distracters.

### Clinical Implications

Making small changes to the organization of a display can substantially impact the efficiency of finding a target in an array (both with the eye and with the mouse). Moreover, these changes reduced the likelihood of fixations to nonrelevant distracters. Both outcomes have important clinical implications.

Median latency to fixate was improved under the clustered display condition by almost 25% in both groups, and the median latency to respond by mouse click to that target was almost 33% faster in those with ASD, and a more moderate 6% in those with DS. Speed of message preparation is a critically important area within AAC, as the rate of message preparation for direct selection in AAC can be as slow as 15 words per minute (as compared to 150–250 words/min for speech). Although we would never argue that display design, by itself, will solve the challenge of slow message preparation, there is now clear and consistent evidence that clustering promotes more efficient search and responding (e.g., Wilkinson et al., 2008, 2014; Wilkinson & McIlvane, 2013). Clearly, the next step in research is to examine how these display changes influence behavior in authentic social interactions to confirm their true clinical implications. This next step is warranted given that these display organization changes are readily made by clinicians, and that their effects have been demonstrated consistently across all groups studied.

The finding that the number of fixations to nonrelevant distracters was significantly reduced in the clustered display condition is of particular clinical relevance. First, when considered together with the findings concerning search/response latency, this finding suggests that visual search in which there are greater numbers of fixations to distracters is associated with longer latencies both to actually find the target with the eye and to respond to that target via mouse click. Moreover, individuals with intellectual disabilities can be susceptible to distraction, either due to failure to inhibit attention to nonrelevant items (which has been reported in DS; Lanfranchi, Carretti, Spanò, & Cornoldi, 2009; Munir, Cornish, & Wilding, 2000) or in some cases due to overselective attention (which occurs across individuals with severe disabilities, including ASD; see Dube & Wilkinson, 2014, for a review focused on implications for AAC).

If the organization of the AAC display itself promotes looks to nonrelevant distracters during search, then this might be presenting an unintended barrier to effective adoption and use. This is of particular relevance when AAC is first introduced to a child. If that child finds the AAC display confusing and the symbols hard to find, it will be unsurprising if the child chooses not to use it and, instead, finds alternative means to communication. For children who are new to AAC, or even for new displays for children who have existing systems, it is critical to consider how the AAC displays are organized in order to foster success (Burack, 1994).

### Scientific Implications

The findings of the current study parallel and extend previous findings concerning the role of clustering symbols by internal color in facilitating visual search as well as response for target symbols (Wilkinson et al., 2014). In particular, the very same mechanisms of attention observed in children with typical development were operative across both individuals with DS and those with ASD: faster fixation to the target and fewer fixations to the nonrelevant distracters when symbols were clustered by internal color. This suggests that the power of clustering to facilitate search is a fundamental and potentially universal mechanism driving visual attention, rather than a developmental or diagnosis-specific phenomenon.

These changes to search/response efficiency under clustered display conditions occurred even with quite high accuracy of selection. This finding is consistent with previous findings regarding the role of these display conditions (e.g., Wilkinson et al., 2014), including several studies examining motor behavior and kinematics of responding that were conducted with college students, for whom the task is exceptionally easy; those studies found the same advantage for response latency under clustered display conditions (e.g., Liang & Wilkinson, 2018; Liang, Wilkinson, & Sainburg, 2019). This suggests that the measure of latency, either to fixate or to respond, can detect the influence of display design with more sensitivity than a measure of accuracy (or, in other words, latency can detect differences even with ceiling performances on accuracy). As noted, speed of finding symbols is important for message preparation; using accuracy alone as a metric may not be detecting important nuances of AAC use. In addition, although all of our participants responded with high accuracy in this task, it seems quite possible—or even likely—that the effects will be magnified if the task were more challenging either due to task demands (e.g., the participant had a larger array to choose from) or due to participant characteristics (participants had more significant impairments).

Finally, this research illustrates the power of eye tracking technologies to highlight important visual perceptual mechanisms underlying interactions between AAC displays and the individuals who use them. Eye tracking technologies are increasingly being used for both clinical access to AAC and to better understand factors contributing to visual attention to these displays, as reviewed in the introduction. This research underscores the value of the latter effort.

### Limitations and Next Steps

The sample size in the current study was fairly small (though similar to other work reporting on eye tracking with individuals with developmental disorders; Wilkinson & Light, 2014). It is possible that we failed to detect a difference between the two participant groups due to the limited sample size. Nonetheless, significant findings of moderate to large size were found for the two experimental conditions that were the key variable of interest, indicating that the sample size was sufficient to detect the differences between the two experimental display conditions. Future studies that expand this research to larger samples would increase the generalizability of the results and allow exploration of potential cross-diagnosis differences.

Although clustering by internal color has now been demonstrated to influence search in individuals both with and without developmental disabilities, there will be times when doing so will not be possible. For instance, we would not suggest that clinicians should violate natural color; rather, clinicians should use their judgment and, when it is possible, cluster based on internal color. Examination of other display features is clearly a valuable future avenue. One such feature is the use of spatial cues to help distinguish symbols that belong to different word class (grammatical) categories. In many current realizations of AAC displays, symbols are arranged in symmetrical row–column grid arrangements, often from left to right by grammatical class. In these arrangements, people/subjects appear in the leftmost column(s), actions in the next column(s), then objects in the next column(s), and descriptors in the rightmost column(s). In most cases, the columns are all equidistant from one another. Might clustering symbols together based on their grammatical word class category positively influence speed of search for subjects versus actions versus objects versus descriptors? For instance, would search be more efficient when the people/subjects appeared clustered together in the upper left quadrant, with the actions in the upper right quadrant, and so forth? Such studies are a potential next step in this line of research.

As with the studies that this research was replicating, the task was a single session; we did not offer participants repeated exposures to the displays, beyond the 16 trials within each block. Thus, our conclusions apply primarily to the "up-front" experience of participants with an AAC display that is new to them. Nonetheless, it is important that small changes to display design can influence performance, right at the outset of a participant's interaction with an AAC display. As noted earlier, an individual new to AAC may not adopt it readily if the displays are hard for them to use, resulting in abandonment of AAC altogether. In addition, there will always be pages that are less frequently used than others (a page related to Halloween, for instance). For pages that are less familiar, the up-front experience offered by display design may be of critical importance. Clearly, however, future research should examine how long it might take for responses under distributed displays to become as efficient as those in the clustered condition. Such studies would present participants with repeated sessions, rather than just one, and observing the pattern of responding over time.

Finally, this task was conducted in a research setting and there was no social interaction component. Clearly, the purpose of AAC is to support communication during authentic social interactions. A critical next step is to determine whether changes to AAC displays such as what are described here would impact outcomes when the AAC displays are actually being used in the complex social environment. Indeed, a current line of research is measuring visual attention via mobile eye tracking glasses—which has the eye tracker embedded within the stem of a pair of eyeglasses—to examine whether visual attention and communication outcomes are influenced by different display designs. These types of studies, that take design features into authentic social interactions, are a clear and important next step.

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## References

**Bedrosian, J. L., Hoag, L. A., & McCoy, K. F.** (2003). Relevance and speed of message delivery trade-offs in augmentative and alternative communication. *Journal of Speech, Language, and Hearing Research, 46,* 800–817.

**Beukelman, D., & Mirenda, P.** (2013). *Augmentative & alternative communication: Supporting children & adults with complex communication needs*. Baltimore, MD: Brookes.

**Brown, J., Thiessen, A., Beukelman, D., & Hux, K.** (2015). Noun representation in AAC grid displays: Visual attention patterns of people with traumatic brain injury. *Augmentative and Alternative Communication, 31,* 15–26.

**Burack, J. A.** (1994). Selective attention deficits in persons with autism: Preliminary evidence of an inefficient attentional lens. *Journal of Abnormal Psychology, 103*(3), 535.

**Dube, W. V., & Wilkinson, K. M.** (2014). The potential influence of stimulus overselectivity in AAC: Information from eye tracking and behavioral studies of attention with individuals with intellectual disabilities. *Augmentative and Alternative Communication, 30,* 172–185.

**Dunn, L. M., & Dunn, D. M.** (2006). *Peabody Picture Vocabulary Test–Fourth Edition*. Circle Pines, MN: AGS.

**Fletcher-Watson, S., Findlay, J. M., Leekam, S. R., & Benson, V.** (2008). Rapid detection of person information in a naturalistic scene. *Perception, 37,* 571–583.

**Hoag, L. A., Bedrosian, J. L., McCoy, K. F., & Johnson, D. E.** (2004). Trade-offs between informativeness and speed of message delivery in augmentative and alternative communication. *Journal of Speech, Language, and Hearing Research, 47,* 1270–1285.

**Johnson, J. M., Inglebret, E., Jones, C., & Ray, J.** (2006). Perspectives of speech language pathologists regarding success versus abandonment of AAC. *Augmentative and Alternative Communication, 22,* 85–99.

**Joseph, R. M., Keehn, B., Connolly, C., Wolfe, J., & Horowitz, T. S.** (2009). Why is visual search superior in autism spectrum disorder. *Developmental Science, 12,* 1083–1096.

**Karatekin, C.** (2007). Eye tracking studies of normative and atypical development. *Developmental Review, 27,* 283–348. https://doi.org/10.1016/j.dr.2007.06.006

**Kent-Walsh, J., Binger, C., & Hasham, Z.** (2010). Effects of parent instruction on the symbolic communication of children using augmentative and alternative communication during storybook reading. *American Journal of Speech-Language Pathology, 19,* 97–107.

**Kent-Walsh, J., & McNaughton, D.** (2005). Communication partner instruction in AAC: Present practices and future directions. *Augmentative and Alternative Communication, 21,* 195–204.

**Lanfranchi, S., Carretti, B., Spanò, G., & Cornoldi, C.** (2009). A specific deficit in visuospatial simultaneous working memory in Down syndrome. *Journal of Intellectual Disability Research, 53,* 474–483.

**Liang, J., & Wilkinson, K. M.** (2018). Gaze toward naturalistic social scenes by individuals with intellectual and developmental disabilities: Implications for augmentative and alternative communication designs. *Journal of Speech, Language, and Hearing Research, 61,* 1157–1170.

**Liang, J., Wilkinson, K. M., & Sainburg, R.** (2019). Cognitive-perceptual load modulates hand selection in left-handers to a greater extent than in right-handers. *Experimental Brain Research, 237,* 389–399.

**Light, J., Binger, C., & Kelford Smith, A.** (1994). Story reading interactions between preschoolers who use AAC and their mothers. *Augmentative and Alternative Communication, 10,* 255–268.

**Munir, F., Cornish, K. M., & Wilding, J.** (2000). A neuropsychological profile of attention deficits in young males with fragile X syndrome. *Neuropsychologia, 38,* 1261–1270.

**Mayer-Johnson, R.** (1992). The picture communication symbols. Solana Beach, CA: Mayer-Johnson Co.

**Schopler, E., Reichler, R. J., & Renner, B. R.** (1988). *The childhood autism rating scale*. Los Angeles, CA: Western Psychological Services.

**Thiessen, A., Beukelman, D., Ullman, C., & Longenecker, M.** (2014). Measurement of the visual attention patterns of people with aphasia: A preliminary investigation of two types of human engagement in photographic images. *Augmentative and Alternative Communication, 30*(2), 120–129.

**Thiessen, A., Brown, J., Beukelman, D., & Hux, K.** (2017). The effect of human engagement depicted in contextual photographs on the visual attention patterns of adults with traumatic brain injury. *Journal of Communication Disorders, 69,* 58–71.

**Thiessen, A., Brown, J., Beukelman, D., Hux, K., & Myers, A.** (2017). Effect of message type on the visual attention of adults with traumatic brain injury. *American Journal of Speech-Language Pathology, 26,* 428–442.

**Venker, C. E., & Kover, S. T.** (2015). An open conversation on using eye-gaze methods in studies of neurodevelopmental disorders. *Journal of Speech, Language, and Hearing Research, 58,* 1719–1732. https://doi.org/10.1044/2015_JSLHR-l-14-0304

**Wilkinson, K. M., Carlin, M., & Thistle, J.** (2008). The role of color cues in facilitating accurate and rapid location of aided symbols by children with and without Down syndrome. *American Journal of Speech-Language Pathology, 17,* 179–193.

**Wilkinson, K. M., & Hennig, S.** (2009). Consideration of cognitive, attentional, and motivational demands in the construction and use of aided AAC systems. In G. Soto & C. Zangari (Eds.), *Practically speaking: Language, literacy, and academic development for students with AAC needs* (pp. 313–334). Baltimore, MD: Brookes.

**Wilkinson, K. M., & Jagaroo, V.** (2004). Contributions of principles of visual cognitive science to AAC system display design. *Augmentative and Alternative Communication, 20,* 123–136.

**Wilkinson, K. M., & Light, J.** (2014). Preliminary study of gaze toward humans in photographs by individuals with autism, Down syndrome, or other intellectual disabilities: Implications for design of visual scene displays. *Augmentative and Alternative Communication, 30,* 130–146.

**Wilkinson, K. M., & McIlvane, W.** (2013). Perceptual factors influence visual search for meaningful symbols in individuals with intellectual disabilities and Down syndrome or autism spectrum disorders. *American Journal on Intellectual and Developmental Disabilities, 118*(5), 353–364.

**Wilkinson, K. M., & Mitchell, T.** (2014). Eye tracking research to answer questions about augmentative and alternative communication assessment and intervention. *Augmentative and Alternative Communication, 30,* 106–119.

**Wilkinson, K. M., O'Neill, T., & McIlvane, W. J.** (2014). Eye-tracking measures reveal how changes in the design of aided AAC displays influence the efficiency of locating symbols by school-age children without disabilities. *Journal of Speech, Language, and Hearing Research, 57*(2), 455–466.

**Wilkinson, K. M., & Light, J.** (2011). Preliminary investigation of visual attention to human figures in photographs: Potential considerations for the design if aided AAC visual scene displays. *Journal of Speech, Language, and Hearing Research, 54,* 1644–1657.