VISUAL DISENGAGEMENT AND WORD LEARNING
IN CHIDREN WITH AUTISM SPECTRUM DISORDER

By

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**ABSTRACT**

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This current project discusses correlations between visual attention and word learning in children with autism spectrum disorders (ASD) and children with typical development (TD). The study examined the role of visual disengagement, specifically the difficulty some children have with breaking visual attention to a fixed stimulus. Participants were 19 children with ASD (age 4-7) and 21 children with TD (age 2-7). Eye tracking was used to examine word learning and visual attention. Novel word learning and visual disengagement were significantly correlated in the children with ASD ($r$ = -0.43, one-tailed $p$ = 0.03) when considering the timeout trials but were not significantly correlated in the children with TD ($r$ = -0.19, one-tailed $p$ = 0.21). However, the correlation between novel word learning and visual disengagement in children with ASD was no longer significant after controlling for age. Results suggest that it is important to consider the role of attention in word learning for children with ASD.

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# INTRODUCTION

## Autism and Language

According to the Diagnostic and Statistical Manual of Mental Disorders (5th ed.; *DSM-5*; American Psychiatric Association, 2013) a diagnosis of autism spectrum disorder (ASD) is given to an individual who presents with symptoms in early development that include persistent deficits in social communication and social interaction as well as restricted and repetitive patterns of behavior, interests, or activities. It is important to note that although structural aspects of language are no longer a part of the diagnostic criteria for the neurodevelopmental condition of ASD in the DSM-5, many children with ASD do present with language delays (Tager-Flusberg, Paul, & Lord, 2005). Tager-Flusberg et al. (2005) note that communication for children with autism differs from that of children with typical development by age two. As is the case for children with typical development, there is still variability in language skills and delays for children with ASD. Some individuals with ASD have an unusually rich knowledge of vocabulary, while others are delayed in vocabulary acquisition (Tager-Flusberg et al., 2005). Additionally, children with ASD have been found to understand more words than they produce (Tager-Flusberg et al., 2005). In investigating this further, Venker, Kover, and Ellis Weismer (2016) found that the children who verbally produced the target and children who demonstrated comprehension of the target did not differ significantly in language outcomes. Investigating language in children with ASD is significant because vocabulary knowledge is fundamental for academic success, communicating with others, and expressing wants and needs.

The current project continues this work by integrating two areas of study: word learning and visual disengagement. Work by Venker (2017) has begun to examine a potential association between visual disengagement and language by presenting findings that poorer visual disengagement skills were associated with spoken word recognition in children with ASD. This study will further examine if there is also an association between visual disengagement and novel word learning. The theoretical framework of statistical learning will drive the examination of word learning. According to Aslin (2016), statistical learning involves no explicit instruction, reinforcement or feedback, but rather it is an implicit mechanism of gathering information by mere exposure. The theoretical framework presented by Keehn, Muller, and Townsend (2013) will drive the examination of visual disengagement. This model suggests that impaired disengagement of attention may have cascading effects on many areas of development for individuals with ASD, including language.

**Word-Learning**

Researchers have become interested in how children with ASD are learning words, and if their processes of word learning differ from children with typical development. As children develop language, a variety of lexical acquisition mechanisms may contribute to their word-learning (Arunachalam & Luyster, 2016). Word learning can occur with minimal exposure to stimuli, as shown in mechanisms such as fast-mapping, or with exposure to stimuli across multiple occurrences as shown in cross-situational statistical learning mechanisms (Carey & Bartlett, 1978; McGregor, Rost, Arenas, Farris-Trimble, & Stiles, 2013). In a review by Arunachalam and Luyster (2016), lexical acquisition mechanisms for children with ASD were examined. The researchers found that children with ASD are able to use mechanisms of word learning that children with typical development use, though they may require more time and input to efficiently use these mechanisms when compared to children with typical development.

Evidence that children with ASD are able to utilize mechanisms of word learning was further supported by Kover (2018), describing that children with ASD are able to learn from distributional cues (e.g., phonological patterns, cross-situational learning). Specifically, it is reported in Kover (2018) that children with ASD do not differ in performance from children with TD in object-label association and word segmentation tasks. Performance in word-learning tasks can be improved in children with ASD by ensuring language input is presented in ample amounts and in a manner that is supportive for word-learning through distributional cues (Kover, 2018). To facilitate language learning, input should be presented frequently, in a grammatically complete and natural manner, with a variety of nouns and verbs used (Kover, 2018). Ultimately, both children with typical development and children with ASD are able to use word-learning mechanisms and the current study expands upon this by examining the potential contribution of visual attention in the word-learning process.

**Fast mapping** is a word-learning mechanism that occurs when an association between a new word and its meaning must be created from brief exposure (Carey & Bartlett, 1978). Children who are able to efficiently use fast mapping to learn word-meaning associations may have a language-learning advantage and later present with better expressive and receptive language outcomes, even if they are not producing the newly learned words (Venker et al., 2016). However, the process of fast mapping alone may not commit a new word meaning to memory, and children must engage in a process of extended mapping to truly learn the meaning of a new word (Arunachalam & Luyster, 2016). Both children with typical development and children with ASD have been shown to effectively use fast mapping as a word-learning mechanism (Smith & Yu, 2008; Venker et al., 2016).

**Cross-situational word learning** utilizes information that is gathered from multiple encounters to infer word mappings (McGregor et al., 2013; L. Smith & Yu, 2008). Cross-situational word learning is a specific type of statistical learning. Statistical learning can also be described as the ability to extract statistical regularities from exposures to a stimulus (Arunachalam & Luyster, 2016). As shown in Figure 1-A (Smith, Suanda, & Yu, 2014), co-occurrences of auditory stimuli and visual stimuli are present in the natural world, and patterns can be extracted from these co-occurrences. For example, a young child who is a word learner may learn the word "spoon" by implicitly noticing a pattern in the instances where they see a spoon while also hearing the word "spoon". Figure 1-B (Smith, Suanda, & Yu, 2014) depicts a more structured example of word learning, where two words are presented auditorily while two visual stimuli are on a screen. Similar to the real-world example, a word learner may use cross-situational methods of word learning by noticing patterns in the presentation of the stimuli. For example, the word "bosa" is presented each time a red shape is on the screen and noticing this pattern may assist in the formation of a word-object association.

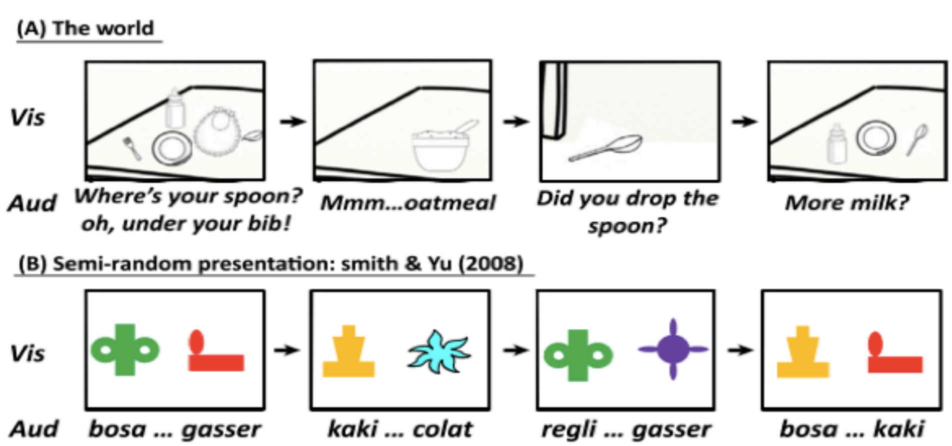


**Figure 1: Word-to-Object Co-Occurrences.** This partial figure from Smith, Suanda, and Yu (2014) demonstrates how co-occurrences between words (labels) and referents (objects) occur in daily life, allowing for patterns between co-occurrences to be identified. These co-occurrences can also be replicated in a semi-random fashion in a research setting.

Cross-situational word learning is a mechanism that can be used by both children with typical development and children with ASD (Arunachalam & Luyster, 2016; Bunce & Scott, 2017; McGregor et al., 2013; Smith & Yu, 2008; Venker, 2019). The use of cross-situational statistics to learn new words has been reported to be effectively used in both infants and toddlers with typical development (Smith & Yu, 2008; Bunce & Scott, 2016). In addition to children with typical development, a study by McGregor et al. (2013) reported that higher functioning individuals with autism (with mean age of 11) were able to utilize cross-situational learning, and accuracy of word mapping did not differ between the group with ASD and the group with typical development. Further, in a study by Venker (2019) preschool and early school-aged children with ASD were able to efficiently learn words by using cross-situational statistics. However, for children with ASD specifically, more input may be required in order to effectively use cross-situational statistical word learning, as they may benefit from a larger amount of co-occurrences between visual stimuli and auditory stimuli in order to form accurate word-object associations (Arunachalam & Luyster, 2016). The current study will continue beyond the ability to use cross-situational word learning by examining how this word-learning mechanism relates to visual attention for both children with ASD and children with typical development.

**Visual Attention**

When considering visual attention in children with ASD, it is important to consider the potential role of social attention. One type of social attention is joint attention, which involves attention of objects or events being shared between communication partners. Social attention and joint attention have been the topic of many research studies and interventions for children with ASD. Compared to children with TD, many children with ASD have difficulty initiating and responding to joint attention, which may result in difficulty with language development

(Bottema-Beutel, 2016). Additionally, social attention may include gaze cues from a communication partner. Social gaze cues can impact word learning by affecting where a learn places their attention, which has been shown to influence learner sensitivity to word-referent mappings when examining children with TD (MacDonald, Yurovsky, & Frank, 2017). However, the present study did not consider social attention or gaze cues as the focus remained on the non-social, domain-general disengagement of visual attention. Non-social attention was examined by including the non-social stimuli of novel objects and by ensuring the adults could not provide social gaze cues during the study.

One type of domain-general attention is visual orienting. Visual orienting has been organized in current literature into three distinct levels: disengagement, shifting, and engagement (Landry & Bryson, 2004; Sacrey, Armstrong, Bryson, & Zwaigenbaum, 2014). Sacrey et al. (2014) describe these three levels in further detail. Disengagement occurs when visual attention to a fixated stimulus is broken, shifting occurs when visual attention is moved from the previously fixated stimulus to a new visual stimulus, and engagement occurs when there is a fixation on the new visual stimulus. Sacrey et al. (2014) further report that these three components of visual attention have been mapped to specific brain regions with visual disengagement involving the parietal cortex, shifting being associated with the superior colliculus of the midbrain, and engagement involving the thalamus.

Typically developing infants have difficulty disengaging from visual stimuli from birth to one month of age, and this has been named “sticky attention” or “obligatory looking” (Sacrey et al., 2014). Smith et al. (2014) reviewed visual disengagement literature in typically developing children and their findings suggest that “sticky” infant attention may inhibit ability to efficiently use cross-situational learning. Further, more flexible visual attention in infants with typical development has been found to be a strong predictor of later vocabulary development (Ellis, Gonzalez, & Deák, 2014). A study investigating attentional disengagement in children with TD (aged 9-15) found that the capacity to disengage visual attention gradually increased as age increased, suggesting that the attentional system becomes more efficient during childhood and continues to improve with age (Van der Stigchel, Hessels, van Elst, & Kemner, 2017).

Disengagement can be examined by researchers with the use of trials which provide a peripheral and central stimulus, often referred to as Gap-Overlap tasks (Landry & Bryson, 2004; Sabatos-DeVito, Schipul, Bulluck, Belger, & Baranek, 2016). The stimuli can be presented with a brief gap of time between the presentation of the central and the peripheral stimulus, or the stimuli can be presented in an overlapping manner where the peripheral stimulus is presented prior to the removal of the central stimulus (Landry & Bryson, 2004; Sabatos-DeVito et al., 2016). In situations with competing stimuli, a child would need to be able to break attention to the first stimuli and shift attention to the second stimulus while the first was still present. Children with ASD ages 4-13 were found to have difficulty in efficiently disengaging their visual attention in order to shift and engage in a new stimulus (Sabatos-DeVito et al., 2016). This failure to disengage visual attention has been a focus for research including children with ASD (Landry & Bryson, 2004; Sacrey et al., 2014).

Landry and Bryson (2004) found that failures to disengage were largely restricted to children with ASD as opposed to children with Down syndrome and typically developing children, and for 20% of trials the children with ASD remained engaged to the initial stimulus for the entire 8-second trial. Their findings were consistent with claims that children with ASD present with the overly focused “sticky” attention that is present in infants. Sabatos-DeVito et al. (2016) also found that disengagement from a central stimulus was less successful for children with ASD relative to typically developing peers, especially if the stimuli were dynamic. Sacrey et al. (2014) suggested that any major differences in findings across studies regarding visual disengagement abilities may be explained by differences in stimuli and testing methods. For example, in a study by Fischer et al. (2015) static stimuli were used in a gap-overlap task and there were no significant differences in attentional disengagement found between the group with typical development and the group with ASD.

Sacrey et al. (2014) reported that children with ASD showed improved ability to disengage on shift trials as compared to overlap trials. Additionally, individuals with ASD were less likely to initially engage in trials that included social stimuli as compared to non-social stimuli (Sacrey et al., 2014). Sabatos-DeVito et al. (2016) added that peripheral saccade reaction times for both children with ASD and children with TD were similar, suggesting that once the visual attention is “unstuck” the speed of shifting visual attention was unaffected. The study by Sabatos-DeVito et al. (2016) also reported fewer shifts overall, likely a result of fewer instances of disengagement. It has further been reported that impairments in visual disengagement could continue into adulthood and could impact novelty processing, arousal, joint attention, social attention, executive functions, and other cognitive and related functions (Sacrey et al., 2014).

**Links Between Visual Attention and Language**

Visual attention and language intertwine when methods of word learning require visual attention in order to be effective. When there is impairment to visual attention, there may be a resulting impairment in language processing and language acquisition (Keehn, Muller, & Townsend, 2013; Venker, 2016). This hypothesis is portrayed in Figure 2 (Keehn et al., 2013) through a model which hypothesizes that impaired disengagement of attention may have cascading effects on multiple areas of development for individuals with ASD, including language. Deficits in joint attention specifically may affect language development for children with ASD as their ability to develop language is contingent upon joint language abilities (Bottema-Beutel, 2016).

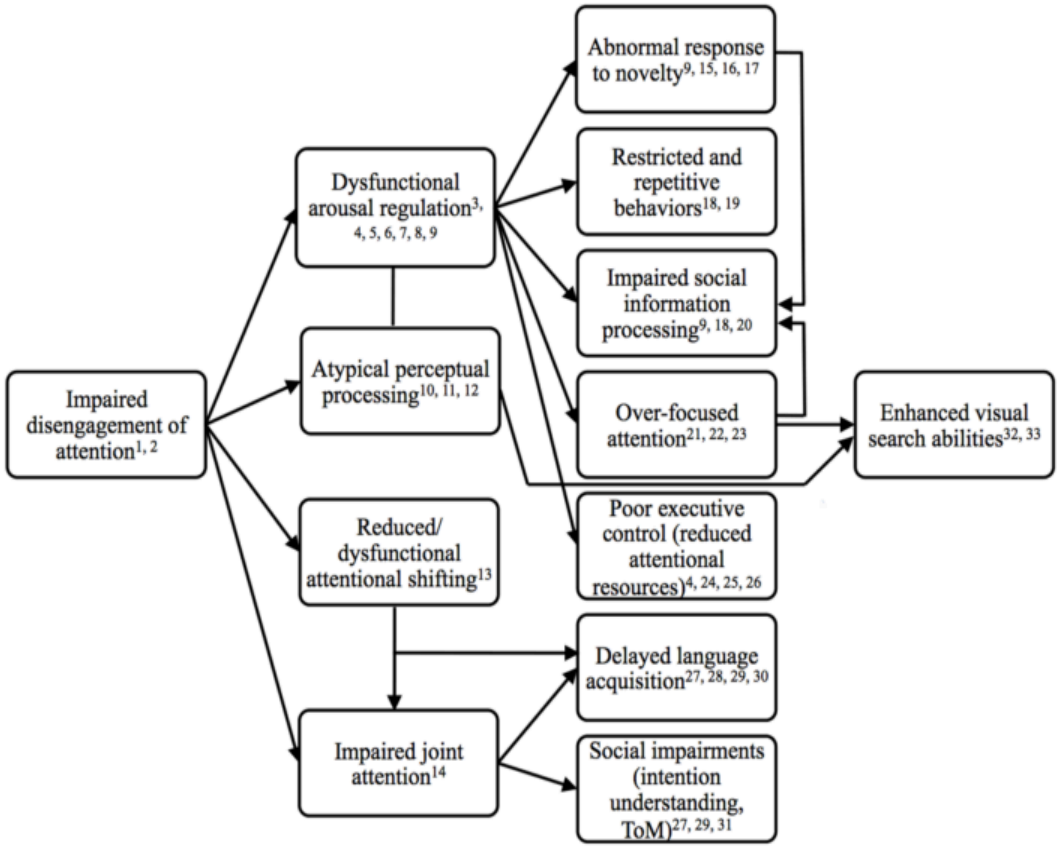


**Figure 2: Developmental Framework Outline.** Figure from Keehn et al. (2013) demonstrating the diverse impact that impaired disengagement of attention may have on many areas of development, including delayed language acquisition.

According to Landry and Bryson (2004), children with ASD have notably had unusual gaze behavior. Further, Arunachalam and Luyster (2016) reported that children with ASD often show deficits that include following gaze, joint attention, and understanding others' internal states, which can be a predictive factor for later language ability. Despite differences in gaze behavior, McGregor et al. (2013) found that children with ASD were able to use gaze in support of word recognition and mapping, with similar patterns of gaze usage between the group with ASD and the group with TD. When children with ASD present with unusual gaze behavior and do not consistently attend to the distributional cues that are essential for word learning, the child may be creating a mismatch of statistical co-occurrences, referred to as auditory-visual misalignment by Venker, Bean, and Kover (2018). This misalignment may impact efficiency of word learning for children with ASD. The current study will expand upon this work by examining potential links between deficits in visual disengagement and language ability.

Language processing was examined in children with ASD using eye-tracking methods in a study by Venker (2017). In the study, Venker (2017) examined the relationship between visual disengagement and spoken word recognition for familiar words. Eighteen children with ASD aged 4-7 were included in the study and participated in a visual orienting task consisting of 10 shift trials and 10 disengage trials. Visual stimuli were presented on screens, with one screen located in front of the participant and one screen on each side (three total screens). Disengagement trials were presented with an overlap between the presentation of the central and side stimuli, and eye gaze was manually coded. Trials in which the child was unable to disengage for the entire length of the trial were referred to as "time out" trials. Spoken word recognition was examined by presenting two familiar images on the central screen and presenting the child with speech such as, "Where is the ball? Do you see it?" and eye gaze data was collected using a Tobii T60XL automatic eye-tracking device and defined areas of interest. Amount of time looking at the target image was used as a variable to examine spoken word recognition. Venker (2017) found that poor visual disengagement, especially in instances of time out trials, was associated with slower and less accurate processing of familiar words for children with ASD. However, it is currently unknown if poor visual disengagement is also associated with processing of newly learned words for children with ASD and children with TD. The current study directly builds on the Venker (2017) results by examining this potential association.

**Eye-Tracking Methodology**

The current study used eye-tracking to measure word learning during the cross-situational task, and to measure visual attention during the disengagement task. Eye-gaze tracking is an emerging method of data collection that has the potential to be used to effectively investigate visual attention and language processing and learning in a non-invasive manner. According to Venker and Kover (2015), methods of eye gaze tracking could potentially be used to access processing in real-time while limiting the number of behavioral tasks required of the participant. Specifically, “attention, memory, face processing, social communication, reading, and language processing and language learning” could be examined using eye-gaze methods (Venker & Kover, 2015). This method accurately estimates the location of the gaze based on the reflection of near-infrared light from the cornea and the pupil that is collected by cameras placed in front of the individual (Falck-Ytter, Bölte, & Gredebäck, 2013). Specific areas of interest are defined to differentiate between the different potential gaze locations.

When using eye-tracking devices to collect data, outcome variables have the potential to be used as predictor variables or to suggest causal relationships, in addition to being used as dependent variables (Venker & Kover, 2015). Eye gaze can tell researchers about language comprehension even when an individual is not producing a target word or verbally demonstrating comprehension of the target by measuring where an individual is looking at specified moments in time, such as when a participant is asked to look at a newly-learned novel object during a cross-situational word learning task (Falck-Ytter et al., 2013; Venker, 2013). These methods provide information about visual and/or auditory attention as the processing occurs rather than responses being captured after the processing has occurred (Venker & Kover, 2015). For these reasons, eye-tracking methods have been used by researchers to investigate visual disengagement in children with autism spectrum disorders (Sabatos-DeVito et al., 2016).

**Current Study**

Previous work by Venker (2017) found that visual disengagement was associated with spoken word recognition for familiar words in children with ASD. The current study will investigate whether this relationship is also present for newly learned words in children with typical development and children with ASD. Specifically, this project will examine two research questions: 1) Is visual disengagement associated with novel word recognition in children with typical development? If so, does this association remain significant after controlling for other factors such as nonverbal IQ and age? 2) Is visual disengagement associated with novel word recognition in children with ASD? If so, does this association remain significant after controlling for other factors such as nonverbal IQ and age?

Based on existing findings (Van der Stigchel et al., 2017; Venker, 2017) it was hypothesized that visual disengagement will be significantly correlated with novel word recognition in children with typical development, such that children with better disengagement would show better word learning. For the second research question, it is hypothesized that visual disengagement will be significantly correlated with novel word recognition in children with ASD, such that children with better disengagement would show better word learning. While the hypotheses for both groups are similar, it is predicted that the significance will be stronger in the group with ASD. This hypothesis was informed by Venker (2017) where children with ASD who demonstrated poorer visual disengagement were slower and less accurate at processing familiar words.

# METHODS

## Participants

The current project used an existing dataset from a study that was conducted at the University of Wisconsin-Madison (Venker, 2013). Data was collected from two groups of children. The first group consisted of 20 children with ASD (age 4-7) and the second consisted of 27 children with typical development (age 2-7). After data processing, the final sample of participants that were included in analysis consisted of 19 children with ASD and 21 children with TD. Children in the ASD group had a diagnosis of ASD as indicated by parent report and confirmed with Autism Diagnostic Observation Schedule, Second Edition (ADOS-2). Children in the TD group did not have diagnoses of ASD, further confirmed through parent completion of the Social Communication Questionnaire (SCQ). The SCQ is a screening measure for ASD with a score of 15 or greater indicating that an ASD evaluation may be appropriate. All children in the TD group received a score below 15. All participants were speakers of English and were excluded for uncorrected vision, hearing impairments, known chromosomal abnormalities, or cerebral palsy. Participants in the TD group were excluded if parents had reported any delay in their development. Participant demographics of the children who provided sufficient data for analysis are listed in Table 1.

| | TD Group (n=21) | | ASD Group (n=19) | |
|---|---|---|---|---|
| | Mean (SD) | Range | Mean (SD) | Range |
| Age (months) | 58 (20.9) | 31-95 | 76 (16.6) | 48-95 |
| PPVT Standard Score | 120 (10.5) | 99-143 | 94 (19.6) | 62-122 |
| PPVT Age Equivalent (months) | 76 (24.8) | 42-115 | 70 (25.4) | 22-113 |
| Leiter Brief IQ | 120 (13.1) | 93-145 | 95 (18.6) | 60-133 |
| ADOS-2 Calibrated Severity Score | N/A | N/A | 7.4 (1.7) | 5-10 |

**Table 1: Participant Characteristics.** Included are the characteristics of the 40 children included in analysis. The abbreviation PPVT refers to the Peabody Picture Vocabulary Test. The Leiter Brief IQ refers to the Leiter International Performance Scale-Revised. The ADOS-2 abbreviation refers to the Autism Diagnostic Observation Schedule, 2nd edition.

**Testing**

Participants completed the study in a single visit. Experimental tasks included a cross-situational word-learning task (two objects and two words were presented), a visual paired comparison task, a simple word-learning task (one object and one word were presented), and a visual orienting gap-overlap task. The current study focused on the cross-situational word-learning task and the visual orienting task. In addition to these tasks, the Peabody Picture Vocabulary Test (PPVT) was administered to measure participant's vocabulary comprehension. The Leiter International Performance Scale-Revised was used to assess nonverbal cognitive abilities. Parents were also asked to complete the Vineland Adaptive Behavior Scales and Social Communication Questionnaire.

**The cross-situational word-learning task** was similar to that used by Smith and Yu (2008). Participants completed the task in a soundproof booth, and a Tobii T60XL Eye Tracker (Tobii) was used to record eye gaze. Visual stimuli were presented on a monitor and consisted of three pictures of familiar objects (*ball, cup, shoe*) and four pictures of novel objects (as shown in Figure 3). Auditory stimuli were presented through computer speakers and consisted of the labels to the three familiar pictures (*ball, cup, shoe*), and four novel words for the novel objects (*bosa, coro, manu, peri*).

**Figure 3: Familiar and Novel Images.** Examples of objects used in the familiar word trials are shown on the top of the image. Examples of novel objects to be used in the word-learning trials are shown on the bottom of the image (Venker, 2013).

The task included three phases. A familiarization phase allowed children to experience the task design (see Figure 4), a training phase presented novel images and auditory labels in pairs with no indication of direct label-object associations, and the testing phase examined if the children were able to create the label-object associations for the objects during the training phase. During the training phase, novel objects and labels were presented in pairs in order to facilitate cross-situational learning by providing co-occurrences of labels and objects. During the testing phase, children heard a verbal prompt (such as, "Where is the manu? Do you like it?"), and data were collected from the eye gaze of the participants during this task. Children demonstrated word learning by looking at the named object during this task. There were 16 trials during the testing phase.

**Figure 4: Cross-Situational Task Completion**. Example of child completing a cross-situational task from Venker (2013). The two objects shown reflect objects the child saw on a screen, with the camera showing researchers the direction of his visual attention.

Groups were matched on receptive vocabulary. Based on related literature (Fernald, Zangl, Portillo, & Marchman, 2008; Venker, 2017), accuracy in the testing phase of the word-learning task was defined as the proportion of time that children spent looking at the named object compared to total time spent looking at either the named or unnamed object during the set time window of 200ms to 1800ms.

**A visual orienting gap-overlap task** was modeled after a task used by Landry and Bryson (2004). Three screens were utilized to present stimuli, with one large screen in the center and two smaller screens, one for each periphery. Visual stimuli included colorful and dynamic shape patterns from movie clips, and there were no auditory stimuli. There were 10 gap and 10 overlap trials in this task. Gap trials measured shifting of attention and were presented with a short gap between the presentation of the central and peripheral stimuli. Overlap trials measured disengagement of attention by presenting the peripheral stimuli before the central stimuli were removed, requiring the child to shift visual attention while the center stimulus was presenting. For the visual orienting task, variables included the mean latency for disengage (overlap) trials and the proportion of timeout trials where a child never disengaged from the central stimulus for the duration of the 8-second trial. The variables were positively skewed, and therefore were transformed into natural logarithms to more closely approximate normal distribution.

An example of an overlap trial is shown in Figure 5 (Venker, 2013) where the child is presented with a central and a peripheral stimulus in an overlapping manner. Eye gaze was coded manually for this task, only including in the analysis the trials that were identified as valid by the two trained coders. The exclusion of invalid trials occurred if the child was not looking at the screens when the stimulus appeared, if they were shifting their attention prior to the stimulus presentation, or if they were first attending to the blank side screen. Interrater agreement of valid trial identification between the two coders was 96.25% for both the group with ASD and the group with TD. Coders then identified the moment when the child initiated a shift in gaze from the center stimulus to the side stimulus, measuring the latency to shift attention or disengage attention. Interrater agreement of eye gaze shifting was 100% for the group with ASD and 97.92% for the group with TD.


**Figure 5: Gap-Overlap Task Completion.** Example of a child completing the gap-overlap test which examines visual disengagement. The three boxes on the bottom relect three screens where stimuli were presented. The child in this example is visually “stuck” on the middle screen and is not visually attending to stimuli on the peripheral screen (Venker, 2013).

## Data Processing

Data were filtered, cleaned, and analyzed using R and R-Studio software systems. An interpolation script was run to account for participant blinks in eye-tracking data, so results were not negatively altered by gaps (blinks) in data gathered from eye-gaze toward target objects. Data files were consolidated, summarized, and aggregated to allow for easier data analysis. A test window of 200ms to 1800ms was set for data analysis.

Minimum criteria was set for trial inclusion based on previous work by Venker and Kover (2015). This included exclusions first at the trial level, and then at the participant level. There are no explicit recommendations for minimum criteria for this area of research, which is an important issue as there are no existing standards. The quality of data is largely based on instances of inattention. Missing data occur when a child is not looking for a considerable amount of time, or for a considerable number of trials. A child needed to look at the screen for at least half of the time during the analysis window of 200ms to 1800ms for the trial to be valid. Children who did not provide at least 2 valid trials in both the word-learning task and visual orienting task were not included in analysis. Ultimately, 19 children in the group with ASD and 21 children in the group with TD were included in analysis.

As noted above, a proportion valid value of 0.5 was set as the required proportion of time the participant was to be looking at the stimuli, rather than at the background or away from the targets entirely. Children who provided fewer than 2 trials were excluded from analysis. On average, the children with ASD looked at the images 79.2% of the time (*SD* = 11.0%) and the children with TD looked at the images 87.2% of the time (*SD* = 4.0%) during the cross-situational task. After data cleaning for the cross-situational task, the children with ASD included in analysis contributed a mean of 7.74 trials (*SD* = 4.7) of the 16 possible trials, and the children with TD contributed mean of 9.3 trials (*SD* = 3.8). For the gap-overlap task, children in the TD group contributed a mean of 8.58 overlap trials (*SD* = 1.33) and children in the ASD group contributed a mean of 7.4 overlap trials (*SD* = 1.76).

**Statistical Analysis**

To assess correlations between visual attention and word-learning, R and R-Studio were used. Both research questions were addressed using correlational analyses. One primary regression analysis was conducted per group of participants, with one secondary analysis to determine any potential contributions of age and IQ. One-tailed tests were used in analyzing correlations, based on our predictions about the directionality of the effects. The correlation between cross-situational data and disengagement data (timeout percentage and reaction time) was examined for both the group with ASD and the group with TD. If the correlation was significant, variables such as age and IQ were then further examined for further correlations.

## RESULTS

### Group with TD

The first research question asked if visual disengagement was associated with novel word recognition in children with typical development. To examine this, a regression analysis was used with the independent variable of accuracy during cross-situational tasks and the dependent variable of visual disengagement, considering the two variables of latency and percentage of timeout trials in analysis of visual disengagement. Contrary to predictions, novel word learning and visual disengagement were not significantly correlated in the children with typical development when examining percentage of timeout trials ($r = -0.19$, one-tailed $p = 0.21$), as shown in Figure 6. Novel word learning and visual disengagement were also not significantly correlated when considering the latency variable of disengagement ($r = 0.11$, one-tailed $p = 0.32$), as shown in Figure 7.

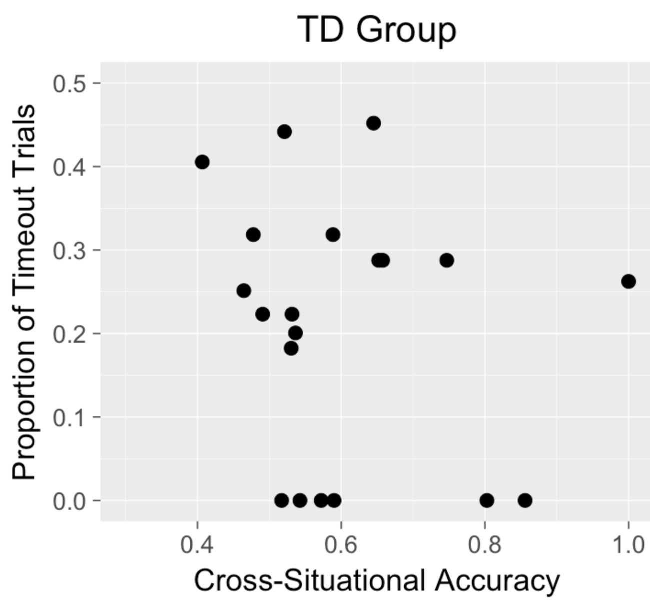


**Figure 6: Cross-Situational Accuracy and Timeout Trials, TD Group.** Scatterplot displays the correlation between accuracy on the cross-situational task and the percentage of timeout trials during the gap-overlap task for the group with typical development.

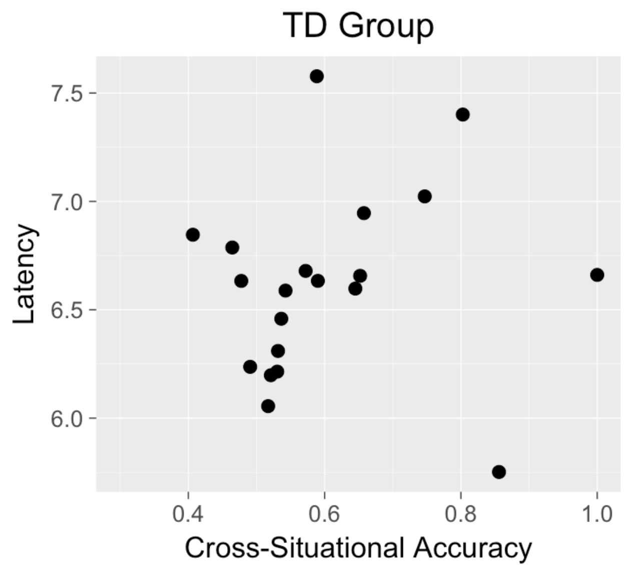


**Figure 7: Cross-Situational Accuracy and Latency, TD Group.** Scatterplot displays the correlation between accuracy on the cross-situational task and the latency duration during the gap-overlap task for the group with typical development.

Although the correlations in the primary research question were not significant, analyses were conducted on the control variables of IQ and age in order to support interpretation of results in the ASD group. Interestingly, there was a significant correlation between the cross-situational task and age ($r = 0.71$, $p < 0.001$) but there was not a significant correlation between the cross-situational task and IQ ($r = -0.35$, $p = 0.118$) for the group with TD. For the visual disengagement task, there was not a significant correlation between disengagement and age ($r = -0.43$, $p = 0.056$) or between disengagement and IQ ($r = 0.21$, $p = 0.358$).

**Group with ASD**

The second research question asked if visual disengagement was associated with novel word recognition in children with ASD. A regression analysis was used to examine the research question with the independent variable of accuracy during cross-situational tasks and the dependent variable of visual disengagement, again considering the two variables of latency and percentage of timeout trials in analysis. As hypothesized, novel word learning and visual disengagement were significantly correlated in the children with ASD when analyzing percentage of timeout trials ($r$ = -0.43, one-tailed $p$ = 0.03), as shown in Figure 8. However, novel word learning and visual disengagement were not significantly correlated when considering the latency variable of disengagement ($r$ = -0.16, one-tailed $p$ = 0.25), as shown in Figure 9.

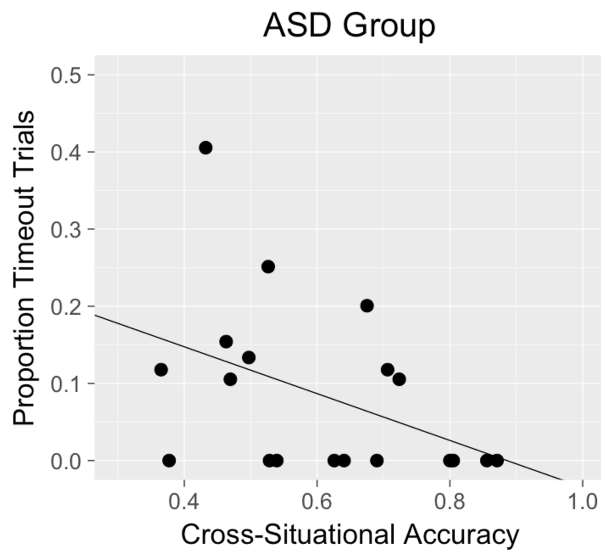


**Figure 8: Cross-Situational Accuracy and Timeout Trials, ASD Group.** Scatterplot displays the correlation between accuracy on the cross-situational task and the percentage of timeout trials during the gap-overlap task for the group with ASD.

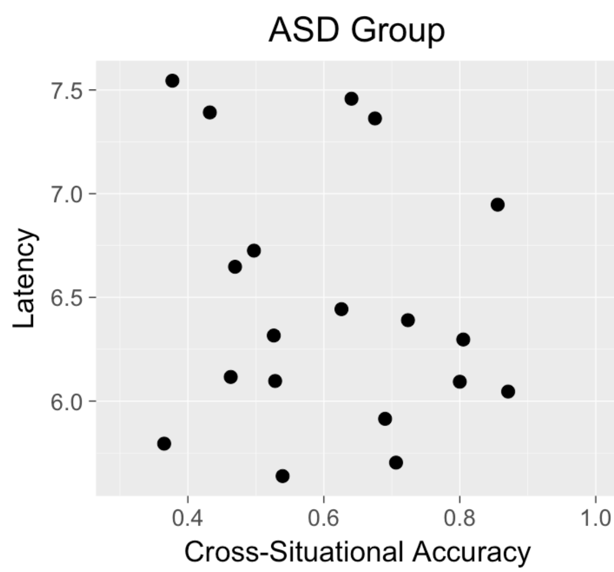


**Figure 9: Cross-Situational Accuracy and Latency, ASD Group.** Scatterplot displays the correlation between accuracy on the cross-situational task and the latency duration during the gap-overlap task for the group with ASD.

Analyses were completed to account for the variables of IQ and age in the ASD group. There was not a significant correlation between the cross-situational task accuracy and age ($r$ = 0.39, $p$ = 0.103) or between the cross-situational task accuracy and IQ ($r$ = 0.25, $p$ = 0.298). There was not a significant correlation between disengagement and IQ ($r$ = 0.16, $p$ = 0.507) when examining the latency variable. However, there was a significant correlation between disengagement and age in the group with ASD ($r$ = -0.63, $p$ = 0.004) when considering the proportion of timeout trials. To examine this further, a regression analysis was completed, revealing that the correlation between disengagement and the cross-situational task accuracy was no longer significant after controlling for age ($p$ = 0.293).

## DISCUSSION

Building on previous evidence that visual disengagement and familiar word recognition are correlated in children with ASD by Venker (2017), the current study examined the relationship between visual disengagement and novel word learning for children with ASD and children with TD. A cross-situational word-learning task was used to investigate novel word learning, and a gap-overlap task was used to investigate visual disengagement.

As predicted, the children with ASD who showed better disengagement demonstrated better novel word learning in the cross-situational task when considering the proportion of timeout trials. However, the latency variable of visual disengagement did not significantly correlate with word learning for the children with ASD. This finding is consistent with findings in Venker (2017) where children who showed better disengagement also demonstrated better familiar word recognition. These results, along with the results from the present study, further emphasize that visual attention does play a role in word learning for children with ASD and should be considered further. Visual attention was essential during the cross-situational word learning task in both the teaching phase and the testing phase. In the teaching phase, the children had to direct their visual attention to the objects in order to effectively learn the target items. In the testing phase, children had to use visual attention as a measure of demonstrating what they learned during the teaching phase. A child with "sticky" visual attention may present with difficulty in either phase of the cross-situational task, as visual attention is important for both learning and for demonstrating that learning occurred. If a child was unable to disengage their visual attention during the learning phase, the learning process may be affected as the children may not pick up on the associations that were present. Additionally, if a child was unable to disengage visual attention during the testing phase, the child may not demonstrate that learning had occurred - even if the child did successfully learn during the teaching phase.

Contrary to predictions, visual disengagement and novel word learning were not significantly correlated in the children with TD. This may be due to the variability of performance within the group, as some children were able to demonstrate successful novel word learning through cross-situational tasks regardless of performance on visual disengagement tasks. It is difficult to determine if these results suggest that visual attention does not play a large role in word learning for this population, as the methods of this particular study may not have fully identified the role of visual disengagement in word learning for children with TD. Further, the role of visual disengagement in word learning may vary in importance at different stages of development for children with TD, which was not specifically investigated in the present study.

As described by Smith, Suanda, and Yu (2014), cross-situational word learning is a type of statistical learning. When a child is trying to learn a new word in a cross-situational context, there are likely many other labels and objects present. If a child has a misalignment between visually attending to an object and noting the co-occurring label, word learning may not be as efficient (Venker et al., 2018). This may be the case for the children with ASD who did not demonstrate visual disengagement and remained visually "stuck" on only one object in the cross-situational word-learning tasks. Due to this, the child may be inconsistently associating labels with objects in this context. When the child is unable to disengage from visual stimuli while learning a new word in a cross-situational context, they may not make accurate word-referent associations as they hear a label for an object that differs from where they are visually attending, further hindering their effectiveness in learning in the cross-situational context.

When considering the two variables involved in visual disengagement, the timeout percentage and the latency time, it was found for both the group with TD and the group with ASD that the latency variable was not significantly associated with novel word learning, but the proportion of timeout trials was significantly associated with novel word learning for the children with ASD. This aligns with the work by Sabatos-DeVito et al. (2016) that discussed how the speed of shifting visual attention was similar for children with TD and children with ASD once the visual attention was "unstuck" from the visual stimulus. This may suggest that the role of visual attention in word learning for children with ASD is less dependent on the speed or efficiency of shifting visual attention, but rather if the child is able to shift their visual attention at all. In future studies, target variables for analysis may place focus on the visual disengagement piece rather than the latency piece, as the "sticky" visual attention played a more significant role in word learning for children with ASD in this study.

**Social Attention**

Although social attention was not directly investigated in the present study, it is important to consider the potential role social attention has on the experimental tasks. In regard to the cross-situational task, social attention was not included as the adult in the room with the child had vision that was blocked from the task, preventing the adult from providing gaze cues or engaging in joint attention of the items in the task. However, the impact of social cues during cross-situational word learning tasks for children with TD has been investigated by MacDonald et al. (2017). Results from this study suggest that social cues have the ability to alter a child's representation of word-referent pairs, with children forming stronger word-referent hypotheses when given consistent, reliable social cues from adults. In contrast, the present-study maintained a focus on non-social attention and disengagement by not including social cues or gaze cues in the cross-situational word-learning task.

**Control Variables**

To investigate the second part of the research questions, the variables of age and IQ were analyzed to identify any further correlations. When examining the group with TD, the cross-situational word-learning task and age were significantly correlated ($r = 0.71$, $p < 0.001$) and the proportion of timeout trials from the visual disengagement task and age were not significantly correlated ($r = -0.43$, $p = 0.056$). These results suggest that age should be further investigated when considering word-learning and visual disengagement for both children with ASD and children with TD. As reported by Van der Stigchel et al. (2017), children with TD were gradually more efficient at disengaging visual attention as age increased. This may have been a factor in the results of this analysis, suggesting that visual attention and the ability to utilize cross-situational statistics for word learning may improve with increased age. For the group with TD, the remaining control variables considerations were not significatly correlated with timeout trials during the visual disengagement task or with the cross-situational task accuracy. Visual disengagement (proportion of timeout trials) and IQ were not significantly correlated ($r = 0.217$, $p = 0.358$), and the cross-situational task and IQ were not significantly correlated ($r = -0.352$, $p = 0.118$). This suggests that the IQ of participants was not directly related to their performance on the word-learning task or their ability to disengage from visual stimuli.

The control variables of IQ and age were also analyzed for the group with ASD. Only one significant correlation was identified, between visual disengagement and age in the group with ASD ($r = -0.63$, $p = 0.0038$). Because disengagement and word learning were significant for this group, an additional regression analysis was completed, identifying that the correlation was no longer significant after controlling for age ($p = 0.293$). This finding could suggest that the reason cross-situational word-learning and visual disengagement (when considering the proportion of timeout trials) were related due to age. However, in the study by Venker (2017) that examined the relationship between visual disengagement and spoken word recognition, visual disengagement remained significantly correlated with spoken word recognition after controlling for age. In comparing the present study to this finding from Venker (2017), we may consider that the cross-situational word-learning task may be a more fragile representation of a child's word learning, ultimately affecting the results. For the group with ASD, the remaining control variables were not significantly correlated with the cross-situational task or with timeout trials during the visual disengagement task. The cross-situational word-learning task and age were not significantly correlated ($r = 0.385$, $p = 0.103$), the cross-situational task and IQ were not significantly correlated ($r = 0.252$, $p = 0.298$), and the proportion of timeout trials during the visual disengagement task was not significantly correlated with IQ ($r = 0.162$, $p = 0.507$).

**Eye-Gaze Tracking Methods**

According to Venker and Kover (2015), eye-tracking may be particularly appropriate for children with neurodevelopmental disorders, including ASD, as the tasks are not as behaviorally demanding as other forms of data collection. They also may be appropriate for this population as it reduces opportunity to become distressed by examiner requests because it does not require the child to complete advanced motor responses (Falck-Ytter et al., 2013). However, eye gaze tasks could still be difficult to participate in if the individual does not typically prefer unfamiliar environments, transitions, distractions, etc. (Venker & Kover, 2015). In order to encourage sustained attention to the task, brief attention-getter clips can be interspersed every few trials of the experimental task (Venker, 2017). Eye tracking further has the potential to characterize autism with links to underlying cognitive networks as well as to everyday function, as these methods are capable of revealing subtle differences in speed and accuracy of processing (Falck-Ytter et al., 2013; Kylliäinen, Jones, Gomot, Warreyn, & Falck-Ytter, 2014; Venker & Kover, 2015).

The current study used automatic eye-tracking. However, automatic eye-gaze tracking can lead to loss of data in a research study. The current study did lose data by excluding participants during the data cleaning process due to the amount of trials gathered by the automatic eye tracking. This resulted in a sample size that was smaller than anticipated, which was a limitation of the present study. Data collection using eye-gaze tracking can also be completed through manual coding methods. Venker and Kover (2015) outline both methods along with associated benefits and drawbacks for each method. Automatic eye tracking was used as this method accurately estimates the location of the gaze based on the reflection of near-infrared light from the cornea and the pupil that is collected by cameras placed in front of the individual (Falck-Ytter et al., 2013). However, this method of data collection presents with instances of data loss when the tracker is unable to complete light reflections. This can occur if the child closes their eyes, turns their head, or moves themselves from the tracking space. Manual eye-tracking methods involve videotaping the participant and later hand coding the location of the participant's gaze for each frame of the video recording (Venker & Kover, 2015). This method can be used to preserve data from trials that may have been missed by the automatic eye tracker, resulting in a reduction in data loss. In future studies, it may be beneficial to utilize both automatic eye tracking and manual coding to ensure the maximum amount of data is collected to be analyzed.

## Limitations

Participants in this study consisted of a large range of ages, from 31-95 months, which may have limited the results of the study as the variability within ages may have taken away from the investigation of cross-situational task and visual behaviors. This may have affected the results as age was determined to be correlated with the word-learning task for children with ASD, and because visual disengagement skills have been shown to improve with age in children with typical development (Van der Stigchel et al., 2017). The use of automatic eye tracking resulted in data loss due to a lack of trials contributed, which was an additional limitation as it resulted in participant exclusion. Not only did this result in a smaller sample of data to analyze, but the heterogeneity of language skills within the sample of children with ASD was affected. This was because the children with ASD who were excluded from the analyses for not contributing a sufficient amount of trials were also the children who presented with lower levels of receptive vocabulary. In future studies, manual eye-gaze tracking may be considered in order to preserve more trials of data for analysis and to prevent participant exclusion due to data loss.

When considering methodology, the gap-overlap task may have been limited in the amount of trials completed. Additionally, by defining a timeout trial as visual attention that did not disengage for 8 seconds the results may have been affected as there were children in both groups who did not disengage from the initial visual stimulus within the 8 second time frame. In future studies, it may be beneficial to increase this duration in order to best determine which children truly had difficulty from disengaging from visual stimuli. However, it is important to note that children with ASD may not be consistently fixated on a visual stimulus for an extended amount of time. In a study of 6-to-9 month infants, the children with the shortest fixation durations were the children who were later diagnosed with ASD at 36-months (Wass et al., 2015). There were also limitations in the cross-situational learning task. Although children in both groups of participants were able to learn the target words, not all of the participants demonstrated evidence of learning from the task. The task may have been too difficult for efficient word learning to occur, due to the amount of exposure to the stimuli and the number of trials. In the future, it may be beneficial to design the cross-situational learning task to include fewer target words or more trials of each word in order to further support cross-situational word learning of novel words.

**Future Research**

Moving forward, there are remaining questions for potential future research in this area. As noted in the results of this study, age may play a role in word-learning for children as their visual attention patterns mature. It may be beneficial for future studies to investigate the role of age in word learning as it relates to visual attention by including participants from a smaller age range. The present study included word learning of nouns, and future studies are currently being conducted in order to explore how visual attention may also relate to word learning and vocabulary knowledge for other parts of speech, such as verbs (Valleau, Konishi, Golinkoff, Hirsh-Pasek, & Arunachalam, 2018). In identifying that visual attention does play a role in word learning, future research may wish to examine clinical implications in regard to vocabulary instruction. By considering visual attention, researchers may be able to identify more efficient and effective methods of teaching vocabulary to children with ASD. Cross-situational learning has been shown to be used as a successful word learning intervention for increasing vocabulary with late-talking toddlers, and similar work in this area may be beneficial to examine if cross-situational learning could also be effective for children with ASD (Alt, Meyers, Oglivie, Nicholas, & Arizmendi, 2014). Additionally, this may require future work to determine methods for clinicians and teachers to monitor visual attention in therapy or classroom settings.

**Clinical Implications**

Recognizing that children with ASD may require the ability to disengage with visual stimuli to learn new vocabulary has clinical implications for intervention. First, it is important that clinicians and teachers increase awareness of the potential impact visual attention has on word learning. Interactions with children who have difficulty disengaging from visual stimuli should be appropriately adjusted in order to best support these children. Clinicians and teachers could adjust their interactions by observing where the children are looking and giving the children who are "stuck" on visual stimuli time to shift their attention back to the target activity. Further, the presentation of learning opportunities could reflect the patterns of visual attention that the child is contributing, only providing a learning target when the child is visually attending to the task. Children with ASD may require more repetitions of visual input or require modified input in order to learn new vocabulary words efficiently. Additionally, these children may benefit from fewer visual distractions in their learning environment during vocabulary interventions, as their word learning may be disrupted by having their visual attention "stuck" on a non-target item. During sessions, targeting a small number of items at a time may also be supportive of word learning by providing more opportunities to pair objects with their labels, further facilitating cross-situational learning for children with ASD.

# CONCLUSIONS

Ultimately, it is important to consider the role of visual attention in word learning for children with ASD. Cross-situational word-learning requires a child to visually attend to target items in order to be completed efficiently and effectively. Further, if a child is unable to disengage from visual stimuli, utilizing cross-situational contexts for word learning may be more of a challenge than it is for children who are able to easily disengage from visual stimuli. Recognizing that children with ASD learn words differently impacts clinical practice as we can learn how to better instruct word learning for children in this population.

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