Published in final edited form as:
J Autism Dev Disord. 2016 December ; 46(12): 3755–3769. doi:10.1007/s10803-016-2926-y.

Lexical Processing in Toddlers with ASD: Does Weak Central Coherence Play a Role?

Susan Ellis Weismer[a,b], **Eileen Haebig**[a,b,c], **Jan Edwards**[a,b], **Jenny Saffran**[b,d], and **Courtney E. Venker**[b]

[a]Department of Communication Sciences & Disorders, Goodnight Hall, 1975 Willow Drive, Madison, WI 53706 USA

[b]Waisman Center, 1500 Highland Avenue, Madison, WI 53705 USA

[c]Department of Speech, Language, and Hearing Science (postdoctoral fellow currently), Lyles-Porter Hall, 715 Clinic Drive, Purdue University, West Lafayette, IN 47907 USA

[d]Department of Psychology, Brogden Hall, 1202 West Johnson Street, Madison, WI 53706 USA

Abstract

This study investigated whether vocabulary delays in toddlers with autism spectrum disorders (ASD) can be explained by a cognitive style that prioritizes processing of detailed, local features of input over global contextual integration – as claimed by the weak central coherence (WCC) theory. Thirty toddlers with ASD and 30 younger, cognition-matched typical controls participated in a looking-while-listening task that assessed whether perceptual or semantic similarities among named images disrupted word recognition relative to a neutral condition. Overlap of perceptual

---

Correspondence should be sent to Susan Ellis Weismer, 1500 Highland Avenue, Waisman Center, University of Wisconsin-Madison, Madison, WI, USA 53705, phone: 608-263-8861, fax: 608-263-7710, ellisweismer@wisc.edu.
The first author is Susan Ellis Weismer, Department of Communication Sciences & Disorders and Waisman Center, University of Wisconsin-Madison, Madison, WI, USA. The second author is Eileen Haebig, Department of Communication Sciences & Disorders and Waisman Center, University of Wisconsin-Madison, Madison, WI, USA. The third author is Jan Edwards, Department of Communication Sciences & Disorders and Waisman Center, University of Wisconsin-Madison, Madison, WI, USA. The fourth author is Jenny Saffran, Department of Psychology and Waisman Center, University of Wisconsin-Madison, Madison, WI, USA. The fifth author is Courtney E. Venker, Waisman Center, University of Wisconsin-Madison, Madison, WI, USA.
Dr. Eileen Haebig is currently affiliated with the Department of Speech, Language, and Hearing Sciences, Purdue University, West Lafayette, IN, USA.

Compliance with Ethical Standards

Ethical Approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This research project was approved by the Institutional Review Board. Parents provided written informed consent for their child prior to enrollment in the study.

Publication Ethics: This manuscript is not currently under submission at another journal; it reports original data. A portion of the data reported in this manuscript have been reported in another manuscript that is in press at JADD (Brief Report: Early lexical comprehension in young children with ASD: Comparing eye-gaze methodology and parent report, *DOI 10.1007/s10803-016-2747-z*); that study addresses an entirely different, methodologically-focused question and includes only partial data from one of the groups in the current study.

Author contributions: SEW conceived of the study, designed the experiment, wrote the grant application that funded this research, and drafted the manuscript. JE and JRS conceived of and helped coordinate the study, designed the experimental task, wrote the grant application that funded this research, aided in interpretation of the findings, and provided critical feedback on the manuscript. EH helped with data collection, performed statistical analyses, assisted with interpretation of the findings, assisted with drafting the manuscript, and provided critical feedback on the manuscript. CEV performed statistical analyses, assisted with interpretation of the findings, assisted with drafting the manuscript, and provided critical feedback on the manuscript. All authors read and approved the final manuscript.

Conflict of Interest: None of the authors have any conflicts of interest to declare with respect to this research.

features invited local processing whereas semantic overlap invited global processing. With the possible exception of a subset of toddlers who had very low vocabulary skills, these results provide no evidence that WCC is characteristic of lexical processing in toddlers with ASD.

Keywords

autism; lexical processing; weak central coherence; receptive vocabulary; toddlers

Introduction

Language comprehension problems are common in children with autism spectrum disorders (ASD). In fact, a number of studies have found that young children with ASD have relatively more severe delays in language comprehension than in language production (Charman et al. 2003; Ellis Weismer et al. 2010; Hudry et al. 2010; Volden et al. 2011). Many children with ASD have delayed vocabulary acquisition, yet we know very little about lexical processing in this group or the mechanisms underlying it.

On the other hand, there is a considerable amount of research examining lexical processing in typical development. Use of eye-gaze methodology, which allows investigators to track eye movements as children look at visual stimuli while listening to spoken language, has been instrumental in advancing this research. Fernald and colleagues (Fernald et al. 1998; Fernald et al. 2006) have demonstrated a dramatic increase in speed and accuracy of spoken word comprehension during the second year of life. Further, individual differences in efficiency of lexical processing at 18 months predict later language outcomes in typically developing children as well as children at risk for language learning difficulties (Fernald and Marchman 2012; Marchman and Fernald 2008; Marchman et al. 2016). As early as 18 to 24 months of age, word recognition is influenced by phonologically and semantically related words (Arias-Trejo and Plunkett 2009; Mani and Plunkett 2010, 2011; Styles and Plunkett 2009), similar to findings from word recognition studies with adults (e.g., McMurray et al. 2010; Huetting and Altmann, 2005). Finally, young children, like adults, process speech incrementally as it unfolds (Marslen-Wilson and Zwitserlood 1989; Fernald et al, 2001, Mahr et al. 2015; Swingley et al. 1999). Because young children acquire words gradually over time, lexical processing involves both recognizing more words and also becoming more efficient at recognizing the same word in varying contexts (Fernald et al. 2006), including contexts with competing distractors. For example, research with typically developing infants and toddlers demonstrates that perceptual and semantic competition impacts real-time word recognition. Arias-Trejo and Plunkett (2010) assessed the effects of competition on lexical processing in 18- to 24-month-old toddlers using eye-gaze methods. Across conditions the target and distractor image varied with respect to visual perceptual similarity or semantic similarity (category membership) Participants viewed image pairs under four conditions: both perceptually and semantically different (e.g., *ball* vs. *fish*), perceptually similar (objects looked alike) but semantically different (e.g., *ball* vs. *cookie*), perceptually different but semantically similar in that they belonged to the same global category (e.g., *apple* vs. *banana*), and both perceptually and semantically similar (e.g., *dog* vs. *cat*). After the target image was labeled, infants looked more at the target than the distractor image in the first three conditions, but not when the objects were both perceptually and semantically similar. Toddlers looked less at the target image if the distractor image looked perceptually similar and was in the same semantic category, despite parents reporting that their infant understood the words used in the experiment. Furthermore, infants looked away from the target image more quickly if the distractor was perceptually similar to the target. Arias-Trejo and Plunkett (2010) concluded that both visual perceptual and semantic similarity (category membership) influenced lexical processing. Relatedly, Houston-Price and colleagues (2007) found that 18-month-olds successfully comprehended words in an eye-gaze task when the distractor items were words from different taxonomic categories (e.g., *shoe* vs. *fish*), regardless of whether their parents reported the words as known or unknown. In contrast, infants were unable to recognize words reported by their parents as unknown when the distractor items were members of the same semantic category (Styles and Plunkett 2009). Tasks similar to these can provide a means for examining word recognition and lexical organization in young children with ASD.

One long-standing theory of cognitive functioning in ASD that has been drawn on to examine language comprehension problems in children on the autism spectrum is the weak central coherence account (Frith 1989; Happé and Booth 2008; Happé and Frith 2006; see overview by Pellicano 2011). According to this perspective, ASD is characterized by a cognitive style in which there is a bias toward local processing, which compromises higher-level global processing. That is, individuals with ASD have been characterized as focusing on fine-grained detail and having difficulty integrating information within the surrounding context. As noted in a recent article by Eberhardt and Nadig (2016), weak central coherence is an intuitively appealing framework for conceptualizing comprehension problems in children with ASD given that language comprehension requires integration of linguistic content, nonverbal communication, and various types of contextual information.

As discussed below, there is some evidence from prior research with older children and adolescents to support the role of weak central coherence in comprehension deficits, as well as evidence against this explanation. Negative findings have also proven useful in that alternative explanations or possible re-conceptualizations of the weak central coherence account have been proposed (e.g., Happé and Booth 2008; Henderson et al. 2011; Järvinen-Pasley et al. 2008; Mottron et al. 2006). To our knowledge, there is not evidence to suggest that weak central coherence is predictive of later language outcomes. However, there is evidence that comprehension skills are predictive of outcomes for children with ASD (Ray-Subramanian & Ellis Weismer 2012; Venker et al. 2013), which is one of the motivations for investigating mechanisms that might be posited to underlie comprehension. The original, strong form of the weak central coherence theory (Frith 1989) would lead to claims regarding difficulties in contextual integration that would be expected to negatively impact language comprehension. However, as with any cognitive account of autism, varying degrees of expression of this phenotype could be expressed within the population (see empirical evidence for varying degrees of central coherence in both typically developing and ASD children, Booth and Happé 2010). Additionally, the weak form of this account (Happé and Frith 2006, 2008) suggests that enhanced local processing may not be inextricably linked with compromised contextual integration and that this default cognitive style can be overcome with explicit instructions to attend to global rather than local features. Whether or not an enhanced focus on local processing comes at the expense of global processing is unclear as exemplified by the conflicting findings of Hadad and Ziv (2015) and Booth and Happé (2016).

In her summary of the central coherence theory, Pellicano (2011) notes that evidence regarding local processing and global processing abilities in individuals with autism has come from a variety of stimuli across several levels of functioning, including visual and auditory perceptual levels and verbal-semantic levels (p. 237). Similarly, Eberhardt and Nadig (2016) state that the weak central coherence account of ASD has been applied to multiple domains including visual, non-speech auditory, and language processing, such that local processing involves bottom-up processing of discrete information whereas global processing refers to top-down processing to derive meaning. Most of the support for enhanced local processing in ASD has arisen from studies of visual perception. Studies of perceptual processing have often employed Navon-type stimuli. (A Navon figure is a large highly recognizable shape made up of smaller copies of a different shape, such as a single large upper-case “T” that is composed of many copies of lower-case “s”.) Studies using Navon figures provide a classical assessment of local-global perception. Research examining claims of weak central coherence within the linguistic domain have involved semantic/conceptual processing. These studies have typically focused on the ability of children with ASD to integrate contextual information for the purpose of language processing, using stimuli that entailed inference construction within story recall (Norbury and Bishop 2002), lexical ambiguity resolution (Hahn et al. 2015), or sentence completion homograph pronunciation (Happé and Booth 2010).

Various studies have found superior local processing in individuals with ASD compared to neurotypical controls, especially on visuospatial tasks such as the embedded figures task (Happé and Frith 2006; but see White and Saldaña 2011) and visual search tasks (Kaldy et al. 2011; Plaisted et al. 1998; O’Riordan 2004). It also has been reported that children with ASD utilize bottom-up attention strategies to a greater extent than their peers when processing visual information, and this tendency has been found to correlate with their receptive language abilities and autism severity (Amso et al. 2014). Using an eye-tracking paradigm, Amso et al. (2014) found that preschool children with ASD relative to age-matched controls looked more at visually salient image regions regardless of the salience of the social content of the image. These investigators speculated that reliance on bottom-up attention strategies negatively impacts language and social development in ASD.

Within the domain of language there is evidence supporting the weak central coherence theory (Booth and Happé 2010; Norbury and Bishop 2002), as well as evidence challenging this account (Brock et al. 2008; Hala et al. 2007; Norbury 2005). Booth and Happé (2010) reported evidence for weak central coherence in children with high functioning autism (HFA), but not for children with ADHD, based on a sentence completion homograph pronunciation task. Norbury and Bishop (2002) concluded that weak central coherence explained deficits in inferencing during story comprehension and recall in children with HFA. However, based on findings from lexical ambiguity resolution tasks, Norbury (2005) asserted that it was language impairment, rather than ASD diagnosis, that was related to problems with central coherence. Similarly, Brock et al. (2008) found no significant difference in online language processing by adolescents with ASD and controls matched on language, age and cognitive level; instead, reduced sentence context facilitation effects were observed in individuals with weak language abilities regardless of diagnosis. Results of a study by Hahn et al. (2015) indicated that children with ASD who were highly verbal were equivalent to language-matched peers in using context to resolve lexical ambiguity. However, there is also counterevidence regarding the role of language in central coherence. In a recent study, Riches et al. (2016) found that adolescents' ability to process syntactically ambiguous sentences was not associated with language impairment status or ASD status. Bavin et al. (2014) claim that severity of autistic behaviors, rather than level of language abilities, impacts real-time language processing in early school-age children with ASD even after adjusting for language, IQ, and attention. Using an eye-tracking task that presented a target image, phonological competitor, and two unrelated distractors, they reported that children with more severe ASD symptoms demonstrated a significantly lower proportion of looks to target than the TD group, but that there was no difference for those with moderate ASD.

The conflicting results regarding weak central coherence across studies are likely due to the use of different tasks and differing matching criteria for the comparison groups, as well as varying participant characteristics. Prior research employing linguistic tasks has focused on school-aged children or adolescents/adults with HFA. The current study investigates the role of central coherence in language processing of very young children with ASD with a wide range of functioning. To the extent that weak central coherence may characterize ASD, we should explore how early in development this style of cognitive processing is evident. From the perspective of language development, words are the basic building blocks of language so gaining a better understanding of lexical processing in toddlers with ASD will provide insights into their well-documented language comprehension deficits that likely have cascading effects on later language development. Use of implicit eye-gaze methods allows this question to be examined not only in highly verbal toddlers but also those with a wide range of abilities in terms of language, nonverbal cognition, and autism severity.

In summary, there is some evidence for a cognitive processing style in which individuals with ASD display a bias toward more fine-grained, local processing rather than global processing that integrates context to facilitate construction of meaning. We were interested in assessing whether the style of cognitive processing posited by the weak central coherence framework plays a role in lexical processing by toddlers with ASD. That is, we were focused on characterizing early lexical processing in ASD and exploring potential underlying cognitive mechanisms.

Current Study

This study investigated whether early vocabulary delays in toddlers with ASD might be explained, at least in part, by a cognitive style of processing that prioritizes the processing of detailed surface features of input over global contextual integration. Specifically, the current study focused on whether weak central coherence may help explain real-time lexical processing differences in toddlers with ASD. To do this, we examined the extent to which different types of overlap among object noun referents disrupted real-time word recognition during a looking-while-listening task based on the task used by Arias-Trejo and Plunkett (2010). This kind of task taps toddlers' ability to direct their visual attention to named images. Our study evaluated word recognition in a condition in which the images that were presented with spoken words have no apparent relationship to each other and in conditions involving two different types of competitors – those that overlap in terms of the visual perceptual features (e.g., shape, color) and those that overlap in terms of semantic features (category membership). Although both the visual-perceptual factor (perceptual similarity) and the semantic factor (semantic similarity) rely on comparisons between the two images shown on the screen, we reasoned that one condition invites processing focused on local or surface details (whether the two images look the same) and the other condition invites global processing involving integration of lexical/semantic information (whether the two images come from the same category such as food or clothing).

We should clarify that both perceptual processing (e.g., small letters vs. large letter in a Navon figure) and semantic processing (e.g., details in meaning vs. gist) can involve local or global processing. That is, we are not suggesting that differences in levels of processing - perceptual vs. semantic - are synonymous with local vs. global processing styles. Instead, we attempted to build on prior research with typically developing toddlers by using a similar task and stimuli to examine real-time word recognition in toddlers with ASD while also applying hypotheses of the weak central coherence account. This approach is novel in that it crosses levels of processing (perceptual vs. semantic) in an attempt to create conditions that are likely to prompt local or global processing. Whereas studies with older individuals with ASD have instructed them to focus on global rather than local processing, we manipulated features of the stimuli such that distractors that overlapped with the target referent in terms of fine-grained details invited local processing and those that overlapped in semantic category invited global processing.

Additionally, because it has been debated whether language abilities versus ASD diagnosis impacts performance on language-based tasks designed to tap difficulties in central coherence, we examined the role of vocabulary knowledge in cognitive processing styles during lexical processing. The current study addressed the following research questions:

1. In a lexical processing task, are toddlers with ASD more disrupted by perceptually similar distractors that invite local processing and/or less disrupted by semantically related distractors that invite global processing than cognition-matched, typically developing controls?
2. Does receptive vocabulary size influence the extent to which toddlers (ASD and typically developing) are disrupted by perceptually vs. semantically similar distractors during lexical processing for the full sample and for each group separately?

Based on claims from the weak central coherence theory, we hypothesized that a bias toward more detail-focused processing would mean that toddlers with ASD would look less to the target when the distractor image was perceptually similar to the target (had similar surface features such as color and shape). That is, we predicted that toddlers with ASD would be more sensitive to, and therefore more disrupted by, perceptual similarities across target and distractor items. It is possible that the hypothesis could be made in the other direction if ASD toddlers were so adept at distinguishing fine details that they quickly dismissed the perceptually similar image and concentrated their gaze on the target. In either case, the prediction would be that the task should produce a significant group x condition interaction, suggesting distinct word recognition processes in the typically developing and ASD groups. According to weak central coherence claims, toddlers with ASD would also be expected to have reduced global processing and consequently should show minimal disruption by semantically related foils, which require children to extract and integrate information about semantic category relationships.

Finally, we hypothesized that receptive vocabulary size would be related to overall lexical processing performance. That is, we expected toddlers with larger extant vocabularies to perform better than those with smaller vocabularies on this word recognition measure. We focused on receptive (rather than expressive) vocabulary in order to align with the modality of the lexical processing task and the looking-while-listening paradigm. Additionally, for young children with ASD there is considerable evidence for a discrepancy in their comprehension-production profiles (Hudry et al. 2010; Volden et al. 2011) so it would be especially important to be consistent with respect to language modality.

Method

Participants

Participants were 30 toddlers with ASD (24 to 36 months; 6 females) and 30 younger children with typical development (14 to 29 months; 15 females) who were matched on non-verbal cognition. Children in the ASD group were recruited through early intervention programs, doctor’s offices, and a research registry for individuals with developmental disabilities. An experienced psychologist administered the Autism Diagnostic Observation Schedule, 2nd Edition (ADOS-2; Lord, Rutter, et al. 2012) or ADOS-Toddler module (Lord, Luyster, et al. 2012) and the Autism Diagnostic Interview, Revised (ADI-R) or a toddler research version of the ADI-R (Rutter et al. 2003). DSM-5 criteria were used to make a best estimate clinical diagnosis (American Psychiatric Association 2013). Children with known chromosomal abnormalities, cerebral palsy, fetal alcohol syndrome, seizure disorders, or other neurological disorders were excluded. Typically developing (TD) children were recruited through a research registry, research labs, and fliers posted in the community. TD children were excluded if they demonstrated signs of developmental delay based on parental report on a background information form, scored beyond 1 SD of the mean on the Bayley Scales of Infant and Toddler Development – Third Edition (Bayley 2006), or scored above the cutoff on a standardized autism screening measure (described below).

The TD and ASD groups were matched on Bayley-III (Bayley 2006) cognitive raw score, $p = .59$. The average Bayley raw score in the TD group was 59.90 ($SD = 9.03$) and 58.57 ($SD = 10.11$) in the ASD group. We selected Bayley raw scores to match the groups because we were interested in equating general cognitive functioning across groups in order to evaluate differences in cognitive style presumed to be indicative of weak central coherence. That is, we were focused on explicating cognitive mechanisms underlying performance on this lexical processing task. The TD and ASD differed significantly on Bayley composite scores in that some of the children within the ASD group exhibited cognitive delays relative to age expectations; the TD group also had significantly higher vocabulary scores and was significantly younger than the ASD group (see Table 1). Extant vocabulary abilities may well impact real-time lexical processing. Therefore, because our cognitive-matched groups differed on vocabulary level, we included parent reported receptive vocabulary (number of words understood) in our statistical models to account for these differences. By using a combination of matching and statistical approaches for equating groups we were able to assess a wider, more representative range of functioning within the autism spectrum than is typical of many studies.

Procedure

Children participated in two visits no more than three weeks apart. Each visit lasted approximately 2.5 hours for children with ASD and 1 hour for TD children. The Institutional Review Board approved this research and parents provided written informed consent for their children's participation. Activities included two eye-gaze tasks (a task that focused on mispronunciations is not reported in this article) and an assessment of nonverbal cognitive ability. Parents completed several questionnaires outlined below.

Clinical Measures

Background Information and Screening—Parents completed a written questionnaire regarding children's medical and treatment history. Parents of children in the TD group completed the Modified Checklist for Autism in Toddlers (M-CHAT; Robins et al. 1999) to assess risk for ASD; scores for children in the TD group did not meet the cutoff for concerns regarding autism spectrum disorder.

Autism Assessment—A research-reliable psychologist administered the ADOS-2 to children in the ASD group. Depending on age and language level, children received Module 1 or 2 (Lord, Rutter, et al. 2012) or the Toddler Module (Lord, Luyster, et al. 2012).

Cognition—Cognitive skills were evaluated using the Cognitive Scale of the Bayley Scales of Infant and Toddler Development – Third Edition (Bayley 2006). The Bayley-III is a psychometrically sound, developmentally appropriate assessment for ages 1–42 months.

Language—All parents completed the MacArthur-Bates Communicative Development Inventories (Words and Gestures form; Fenson et al. 2007) to provide a measure of lexical comprehension and production.

Experimental Task

Eye-gaze paradigm—A looking-while-listening task (Fernald et al. 2008) was used to assess lexical processing. Children completed one block of this task on both days to increase the total number of trials. On each trial, children viewed a pair of images placed in grey boxes in the lower left and right corners of the screen. After two seconds of silence, the target image was labeled (e.g., *See the hat?*), followed by a tag phrase (e.g., *That's great!*). Children had approximately 2 seconds to examine the pictures after the offset of the target noun. Each trial lasted 5 seconds. Children sat on their parent's lap in front of a wallmounted 55-inch television screen. Auditory stimuli were presented by a speaker at approximately 63 dB. Eye movements were recorded by a digital video camera for offline coding (see below). Parents wore opaque sunglasses to prevent them from seeing the visual stimuli and were instructed not to repeat any of the words they heard and not to point at the screen.

Visual Stimuli—Color images depicting each target noun were selected through an online image search. Adult judgments of picture stimuli were obtained to determine prototypical exemplars of an object (e.g., shoe) that would be familiar to a young child. Images were edited in Photoshop to ensure that they were similarly sized. To enhance visibility, images were presented on grey boxes in the lower left and right corners of a black screen (see Figure 1).

Verbal Stimuli—Table 2 lists the stimulus words for each of the task conditions described below. Most of the words were drawn from the Arias-Trejo and Plunkett (2010) study but we switched out British English words for American English in a few cases (e.g., replaced "biscuit" with "cracker" and "cookie") as well as adding a couple of new words. In the current study we established familiarity through the use of Wordbank (http://wordbank.stanford.edu/, formerly LEX), an open database of information about vocabulary development in young children based on archived data from the MacArthur-Bates Communication Development Inventory. According to Wordbank norms for typically developing children, words used in the present study were comprehended or produced on average by 79% (range 38–100%) of 18 month olds (and thus should be quite familiar to our somewhat older participants). Stimulus words were also selected based on local norms for toddlers with ASD (N=129) at approximately 30 months (removed for blind review); the words included in the task were comprehended or produced on average by 48% (range 22–86%) of toddlers with ASD. All noun pairs were phonologically dissimilar (e.g., different initial consonants, no rhymes). With respect to semantic similarity, we used basic level terms for categories that TD infants aged 18–24 months had been shown to understand in prior research (e.g., 'cookie' and 'cheese' from the 'food' category). The categories included in the Semantically Similar condition (described below) were food, clothing, animals, dishes, utensils, toys, vehicles, furniture, and body parts. All of the categories were ones employed in the Arias-Trejo and Plunkett (2010) study with the exception of body parts ('nose', 'mouth'). Perceptual similarity was established by having adult judges view images on a large screen to select pairs that 'looked most alike.'

Task Conditions—The current task was adapted from Arias-Trejo and Plunkett (2010). The task included three conditions: Semantically Similar (SS), Perceptually Similar (PS), and Neutral. A given condition presented 24 different words, each of which served as both target and distracter. In all but one instance the target words appeared in at least two of the conditions. In the SS condition, the target and distractor items belonged to the same global category, such as clothing (e.g., *hat, boot*), but the pictures were perceptually distinct. In the PS condition, the two pictures were perceptually similar (e.g., *banana*, *crescent moon*) but were semantically unrelated. In the Neutral condition, the target and distractor were neither semantically nor perceptually related (e.g., *hat, fish*). The familiarity of the target nouns was balanced across the three conditions, based on parent report of comprehension (CDI scores) for toddlers with ASD collected as part of a prior investigation (removed for blind review). That is, an attempt was made to roughly equate the mean percentage of toddlers who were expected to have the target words in their vocabulary across the three task conditions (Neutral: ASD=50%, TD=81%; SS: ASD=52%, TD=82%; PS: ASD=47%, TD=75%).

Children participated in the eye-gaze task on both visits to the lab. The same stimuli were presented in both sessions, but the stimuli that served as target images on the first day served as distractor images on the second day, and vice versa. To ensure that results were not dependent on the order and placement of the stimuli, each version was counterbalanced to create two different orders. Stimuli were presented in a semi-random order with no more than two trials of the same condition occurring sequentially. Attention-getter stimuli were interspersed to maintain engagement; these stimuli consisted of short, visually appealing video/audio clips from the Baby Einstein video series and visually appealing pictures (e.g., hot air balloons) with encouraging audio clips (e.g., “Great job!”). Children were exposed to 12 trials in each of the three conditions on each day, resulting in a total of 24 trials per condition.

Data Coding and Cleaning—Children’s eye movements were coded offline from video by trained coders at a rate of 30 frames per second. Although visual stimuli were visible during coding, coders were blind to auditory stimuli. Looks were coded as left, right, shifting between fixations, or away from the screen (e.g., looking at the ceiling; Fernald et al. 2008). An initial cleaning window was set between 200 and 1800 ms after noun onset. Trials in which children looked at the images less than half of the time during this window were eliminated because they were not considered to provide adequate data. All participants completed the task and met data cleaning criteria, and all stimuli were included in the analyses. In order to maximize the likelihood of obtaining valid data we wanted to include as many trials as possible. Out of a possible 24 trials per condition, children in the TD group each contributed an average of 20.8 trials in the SS condition ($SD = 4.5$), 21.3 trials in the PS condition ($SD = 4.0$), and 21.1 trials in the Neutral condition ($SD = 4.2$). Children in the ASD group each contributed an average of 18.1 trials in the SS condition ($SD = 5.3$), 18.9 trials in the PS condition ($SD = 5.3$), and 18.9 trials in the Neutral condition ($SD = 5.0$). As might be expected, the ASD group tended to contribute fewer valid trials than the TD group but the difference between groups was statistically significant only for the SS condition, $t(58)=2.115$, $p=.039$; group differences for the PS, $t(58)=1.954$, $p=.056$, and Neutral, $t(58)=1.830$, $p=.072$, conditions were not significant.

Coding Agreement

Videos from six children in each group (20%) were randomly selected and coded independently by two coders. The percentage of initially comparable trials (i.e., trials in which the same number of looks had been recorded) was 83% in the TD group and 79% in the ASD group. Trials that were not initially comparable were discussed and consensus coded. Two measures of inter-coder agreement were derived: frame agreement, which compared all frames; and shift agreement, which compared shifting frames. For the TD group, frame agreement was 98%, and shift agreement was 97%. For the ASD group, frame agreement was 97%, and shift agreement was 95%.

Statistical Analyses

We used mixed-effects growth curve analysis to model relative looks to target over time (Mirman, 2014). The dependent variable was the empirical log-odds of looking to the target image relative to the distractor image. For ease of interpretation, the figures present the proportion of looks to target (i.e., time looking at the target image divided by time looking at either image, averaged across trials for each condition). Level 1 predictors were linear, quadratic, and cubic time. Level 2 variables were group (ASD vs. TD) and receptive vocabulary size (CDI number of words understood, mean centered). All models included participant and participant by condition random effects. The TD group was the reference group and the Neutral condition was the reference condition. Thus, the reported coefficients represent the TD group average in the Neutral condition; coefficients for the PS and SS conditions represent the difference between that condition and the Neutral condition for the TD group. We used the z-distribution to evaluate the significance of the t-values ($t >= +/- 1.96$ was considered significant at the .05 level).

The analysis window was empirically defined (Barr, 2008). Based on visual inspection of the grand mean curves, we selected 200 to 1300 ms as the analysis window. Although some previous studies have used a slightly longer time window (e.g., Bergelson and Swingley, 2012; Fernald et al. 2006), we selected this more restricted time window because we were interested in modeling the increases in looks to target, not the shifts back to the distractor at the end of the trial. That is, we were interested in examining word recognition in the context of different types of distractor images (competition) and therefore the most relevant indicator was accuracy/latency of looks to target. Once children had demonstrated a clear pattern of looks to target we considered that to be evidence for recognition (in the face of a neutral or perceptually similar or semantically similar distractor). After the analysis window as looks to target decrease, the appropriate interpretation of the experimental manipulation becomes less obvious and was not relevant to our research question.

Results

First we examined the effects of perceptual similarity and semantic similarity on lexical processing and whether these effects differed by group. Models were run using the R package lme4 (Bates, Mächler, Bolker, & Walker, 2014). Formulas and full model results are presented in the Appendix. As can be observed in Figure 2, both groups increased their looks to the target over time, and both group and condition influenced eye gaze patterns. Model results showed significant effects of linear time ($Estimate = 2.10; SE = 0.31; t = 6.81$) and cubic time ($Estimate = -0.33; SE = 0.10; t = -3.22$), indicating that looks to the target increased across time and peaked towards the end of the test window. There was a significant effect of group on the intercept ($Estimate = -0.32; SE = 0.09; t = -3.43$) and an interaction between group and linear time ($Estimate = -0.88; SE = 0.44; t = -2.01$). These results indicate that the TD group looked more reliably and quickly at the target than the ASD group. There was also a significant effect for both experimental conditions (PS:

Estimate = −0.28; *SE* = 0.07; $t = -3.82$; SS: *Estimate* = −0.24; *SE* = 0.07; $t = -3.21$) indicating that children looked less reliably at the target in the PS and SS conditions than in the Neutral condition. Finally, there was a significant interaction between group and PS condition (*Estimate* = 0 .22; *SE* = 0.11; $t = 2.05$) indicating that the difference between the Neutral condition and the PS condition was larger in the TD group than in the ASD group. It is not entirely clear how to explain this unexpected two-way interaction. The TD group had a *larger gap* between performance on the Neutral condition and the PS condition than the ASD group. As can be seen in Figure 2, at the beginning of the analysis window (denoted by solid vertical lines), the TD group initially looked toward the distractor in the PS condition. This was not the case for the TD group in either the SS or the Neutral conditions and it was not the case for the ASD group in any of the three conditions. It is possible that this finding supports the alternative hypothesis regarding enhanced processing by the ASD group in the PS condition due to rapid dismissal of distractors that overlap in surface details with the target. However, before assuming this interpretation it is important to consider the impact of group differences in language level on performance on this word recognition task.

Our second research question pertained to the relationship between receptive vocabulary size and lexical processing. We therefore added receptive vocabulary to the initial model. There was a significant effect of linear time (*Estimate* = 1.80; *SE* = 0.39; $t = 4.60$) indicating that looks to the target increased across time. There was also a significant effect of receptive vocabulary size (*Estimate* = 0.002; *SE* = .00; $t = 2.06$), indicating that children with larger receptive vocabularies, relative to those with smaller vocabularies, looked more reliably at the target. The group effect was no longer significant and there were no significant interactions with group. There was a significant effect for both experimental conditions (PS: *Estimate* = −0.24; *SE* = 0.10; $t = -2.52$; SS: *Estimate* = −0.24; *SE* = 0.10; $t = -2.44$), indicating that children in both groups looked less reliably at the target in the PS and SS conditions than in the Neutral condition when controlling for vocabulary.

Although the groups were matched on nonverbal cognition, the TD group was reported to understand significantly more words than the ASD group. For this reason, we also examined the relationship between vocabulary level and lexical processing separately for each group. The models for the two separate groups were identical to the previous one, except that group was not included as a predictor.

In the ASD group model, there was a significant effect of linear time (*Estimate* = 1.22; *SE* = 0.29; $t = 4.24$), indicating that children increased their looks to the target image during the test window. There were no significant effects of receptive vocabulary or condition. There was, however, a significant three-way interaction among linear time, vocabulary, and the PS condition (*Estimate* = 0.007; *SE* = 0.003; $t = 2.12$) indicating that, as vocabulary size decreased, the difference between linear slope terms in the PS and Neutral conditions increased. That is, children with ASD with smaller vocabularies were more disrupted by the perceptually similar distractors than their ASD peers with larger vocabularies.

Although vocabulary size was a continuous predictor, this result is illustrated in Figure 3 using a median split for vocabulary size. It can be observed that children with ASD with large receptive vocabularies had similar slopes in the Neutral condition and the PS condition.

In contrast, children with ASD with small receptive vocabularies had shallower slopes in the PS condition than the Neutral condition. In fact, the slope in the PS condition for the children with ASD and small receptive vocabularies is nearly flat, indicating that children spent approximately the same amount of time looking at the target and distractor image when the images were perceptually similar. As can be seen from Figure 3, the high-vocabulary ASD subgroup evidenced more variability than the low-vocabulary subgroup. We speculate that the low-vocabulary ASD subgroup displayed less variability because that subgroup had a lower ceiling on their abilities due to a more restricted vocabulary. The other subgroup, with higher vocabulary, had the potential to do well and look to the target appropriately for more of the items, but they may not have been consistent in their behavior – leading to increased variation (larger standard errors).

Because previous work has shown a relationship between autism severity and lexical processing (Bavin et al. 2014), we added autism severity to the model. Autism severity was not a significant predictor, and this model did not provide a significantly better fit than the model containing receptive vocabulary alone ($p = .48$). This indicates that the symptoms of autism do not change how lexical processing is influenced by the various distractor conditions, but receptive vocabulary does influence processing.

In the TD group model, there was a significant effect of linear time ($Estimate = 2.10$; $SE = 0.30$; $t = 6.96$) and cubic time ($Estimate = -0.33$; $SE = 0.10$; $t = -3.22$), indicating increased looking to target across the test window that peaked towards the end of the window (see Figure 4). There was a significant effect of receptive vocabulary ($Estimate = 0.002$; $SE = 0.001$; $t = 2.34$), indicating that TD children with larger receptive vocabularies looked relatively more at the target overall than their peers with smaller vocabularies. Finally, there was a significant effect of both experimental conditions (PS: $Estimate = -0.28$; $SE = 0.08$; $t = -3.59$; SS: $Estimate = -0.24$; $SE = 0.08$; $t = -3.01$), indicating that TD children looked less reliably at the target in the two experimental conditions relative to the Neutral condition.

Discussion

This study investigated whether lexical processing in toddlers with ASD was characterized by weak central coherence and whether differences in lexical processing were associated with receptive vocabulary knowledge. In terms of the first research question, there was not general support for weak central coherence in toddlers with ASD as a group. Based on the weak central coherence theory, we predicted that toddlers with ASD would be more disrupted by stimuli that invited local processing and potentially less disrupted by stimuli inviting global processing in a word recognition task than TD children matched on nonverbal cognition. Contrary to our predictions, there was an unexpected effect of perceptual similarity assumed to promote local processing for the TD group, rather than the ASD group. Both groups of children had higher accuracy of word recognition in the neutral condition than in the semantically similar condition, indicating that they were sensitive to same-category competitors. These results are consistent with prior research with older children with ASD that have failed to reveal problems with central coherence (e.g., Hahn et al. 2015; Henderson et al. 2011; Riches et al. 2015). Similar to Arias-Trejo and Plunkett (2010), we found that perceptual similarity and semantic relatedness of the target and distractor images influenced lexical processing. However, unlike their findings, the TD group in the current study showed reduced looking to the target when either a perceptually or semantically similar distractor was present rather than only when the distractor was *both* perceptually and semantically similar to the target image (a condition we did not test in this study). Although the TD groups in both studies were similar in age, these differences in findings could reflect differing task design, language levels, or the use of a more fine-grained analytic approach in the present investigation.

Although there was no evidence that the ASD toddlers displayed a cognitive processing style characteristic of weak central coherence, toddlers with ASD were less accurate and responded more slowly to familiar words than TD toddlers matched on cognitive level. These results are consistent with prior research showing deficits in lexical processing by older children with ASD (Bavin et al. 2014; Kamio et al. 2007) and vocabulary delays in young children with ASD relative to their developmental level (Charman et al. 2003; Hudry et al. 2010).

Our second research question pertained to the role of receptive vocabulary in lexical processing and cognitive style. Although the TD and ASD groups were matched on cognitive level, their receptive vocabulary skills differed significantly. A second model that included receptive vocabulary size found that overall group differences in accuracy and processing speed were eliminated when vocabulary size was taken into account. In contrast to the findings of Bavin et al. (2014), adding autism severity to the model in addition to receptive vocabulary size did not result in a better model fit (see also Hahn et al. 2015). There are a number of reasons that might explain the conflicting findings across these studies including the differing focus of the research questions and differences in the participants and methods. In particular, Bavin et al. (2014) used non-calibrated ADOS scores to form ASD severity groups and scores from the Social Communication Questionnaire (Rutter et al. 2003), a parent report autism screener, as the index of severity whereas in the current study we used calibrated ADOS severity scores. If weak central coherence was a characteristic of ASD we would expect to see some association with autism severity.

Within-group analyses revealed more insights into condition effects. Although our results did not provide evidence that weak central coherence characterizes lexical processing in the children with ASD as a group, findings from the individual group models leave open the possibility that a subgroup of children with ASD—those with more severe language deficits—may show a style of processing that focuses more strongly on fine-grained details. The influence of perceptual similarity on lexical processing interacted with vocabulary size in children with ASD, but this type of interaction effect between receptive language and perceptually similar distractors was not found for the TD group. Children with ASD who had smaller vocabularies were slower to look at the target image in the Perceptually Similar condition relative to the Neutral condition compared to their ASD peers with larger vocabularies. In fact, children with smaller vocabularies spent approximately the same amount of time looking at the target and distractor images when the images were perceptually similar, thereby showing no clear recognition of the target words in this condition (see Figure 3). This demonstrates that the extent to which children with ASD focus on local details is associated with their receptive vocabulary knowledge. In this study we examined receptive vocabulary size as a factor in word recognition, rather than vocabulary depth because this seemed like an appropriate first step for examining lexical processing in toddlers with ASD. Depth of vocabulary has been studied in older individuals with ASD through definition tasks, rapid category naming, or drawing, but these tasks are not feasible for our age group. Future research might use priming paradigms to explore semantic neighborhood effects, as an index of vocabulary depth, in young children with ASD in relation to word recognition.

These results reveal the importance of considering individual differences in cognitive processing style across children with and without ASD, especially as related to extant vocabulary size. Booth and Happé (2010) reported a range of central coherence in typically developing school-age children as well as variability in older children with ASD. It is possible that bottom-up attentional strategies and a focus on fine-grained details of the visual environment is a less efficient word learning strategy and therefore, children who focus attention on low-level detail in the environment learn fewer words (Amso et al. 2014). Although this hypothesis requires further investigation, some children with ASD may also show this type of processing for other aspects of their environment such as acoustic details of speech input (Järvinen-Pasley et al. 2008), which would negatively affect language learning more generally. Over emphasis on processing of fine-grained details within a given modality could lead to difficulties in integrating information across auditory-visual co-occurrences to learn new words, as in the case of cross-situational statistical learning (Smith & Yu, 2008). Along these same lines, Henderson et al. (2014) have argued that a low-level perceptual processing bias may be “suboptimal for the development of an efficient lexical system” (p.868). They speculated that the enhanced sensitivity that children with ASD in their study displayed to phonological competitors during encoding may have worked against longer-term integration of new lexical representations into their existing lexicon.

Although we did not analyze gaze patterns beyond 1300ms after noun onset, it appeared that children with ASD were more likely than TD children to look back to the distractor at the end of the trial rather than remaining on the target image (see Figure 2). This pattern is consistent with the finding by Bavin et al. (2014) for their ASD-severe group. As suggested by Bavin et al., this might reflect a more detailed processing style by the children with ASD or a preference for attending to visual stimuli (unnamed images) rather than auditory stimuli (images corresponding to the spoken label). The role of stimulus modality has been questioned in research exploring central coherence López and Leekam (2003) and Kamio and Toichi (2000) found semantic facilitation effects in adolescents and young adults with ASD for both visual and verbal tasks, but Kamio and Toichi reported that, unlike the TD controls, individuals with ASD performed significantly better on a picture-word semantic priming task than a word-word task. The current results suggest an even more complicated picture in that the tendency to switch gaze back to the perceptually similar distractors (intended to invite local processing) interacted with vocabulary level for the ASD group.

To summarize, these findings do not provide support for the notion that weak central coherence plays a role in comprehension deficits in toddlers with ASD, with the possible exception of toddlers who have very low vocabulary skills. That is, children with ASD with smaller vocabularies were more disrupted by the perceptually similar distractors than their

ASD peers with larger vocabularies, suggesting that they have a tendency to attend to low-level, surface features of stimuli. These results align with claims about the *role of language* in central coherence (Brock et al., 2008; Hahn et al., 2015; Norbury, 2005). Overall, there was no evidence for differences in response to semantically similar stimuli across groups or for the within-group vocabulary level comparisons. This indicates that toddlers with ASD were capable of contextual integration to the extent that they could make connections between objects that were members of the same global category. The fact that both the TD and ASD groups demonstrated significantly more looks to target in the neutral condition indicates that they were distracted by competitors with either perceptual (PS condition) or semantic (SS condition) similarity with the target. These findings confirm that toddlers are sensitive to competition in their lexical environments and that toddlers with ASD appear to be similar to typically developing toddlers in this regard. Given the sparse amount of research on lexical processing in toddlers with ASD, we can only draw tentative conclusions about clinical implications based on these results. Practitioners should be aware that during assessment, young children’s ability to recognize words may be influenced by the presence of distractors that overlap with the target along various dimensions. In order to avoid such competition effects, distractors (foils) should be maximally distinct from the target unless the intent is to evaluate lexical organization. In conclusion, although there may be an association between low language abilities and a bias towards local processing, the overall results of this study call into question the utility of the weak central coherence framework for helping us understand language comprehension deficits in toddlers with ASD.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This research was funded by the National Institutes of Health and the Graduate School at the University of Wisconsin-Madison: NIDCD R01 DC012513, NICHD R37HD037468, NICHD P30 HD003352 core grant to the Waisman Center, and University of Wisconsin Graduate School Grant #130416. None of the authors have any conflicts of interest. We wish to express sincere thanks to the children and their families for participating in this study. Thanks to Corey Ray-Subramanian and Heidi Sindberg for their clinical expertise, Chris Cox for his assistance with statistical programming, and to our research assistants for their help.

References

American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders. 5. Washington, D.C: Author; 2013.

Amso D, Haas S, Tennebaum E, Markant J, Sheinkopf S. Bottom-up attention orienting in young children with autism. Journal of Autism and Developmental Disorders. 2014; 44:664–673. [PubMed: 23996226]

Arias-Trejo N, Plunkett K. Lexical-semantic priming effects during infancy. Philosophical Transactions of the Royal Society B. 2009; 364:3633–3647.

Arias-Trejo N, Plunkett K. The effects of perceptual similarity and category membership on early word-referent identification. Journal of Experimental Child Psychology. 2010; 105:63–80. [PubMed: 19931091]

Barr DJ. Analyzing “visual world” eyetracking data using multilevel logistic regression. Journal of Memory and Language. 2008; 59:457–474.

Bates, D.; Maechler, M.; Bolker, B.; Walker, S. lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-7. 2014. http://CRAN.R-project.org/package=lme4

Bavin E, Kidd E, Prendergast L, Baker E, Dissanayake C, Prior M. Severity of autism is related to children's language processing. Autism Research. 2014; 7:687–694. [PubMed: 25262588]

Bayley, N. Bayley scales of infant and toddler development. 3. San Antonio, TX: PsychCorp; 2006.

Bergelson E, Swingley D. At 6–9 months, human infants know the meanings of many common nouns. Proceedings of the National Academy of Sciences. 2012; 109:3253–3258.

Booth R, Happe F. "Hunting with a knife and…fork": Examining central coherence in autism, attention deficit/hyperactivity disorder, and typical development with a linguistic task. Journal of Experimental Child Psychology. 2010; 107:377–393. [PubMed: 20655060]

Booth R, Happé F. Evidence of reduced global processing in autism spectrum disorder. Journal of Autism and Developmental Disorders. 2016; doi: 10.1007/s10803-016-2724-6

Brock J, Norbury C, Einav S, Nation K. Do individuals with autism process words in context? Evidence from language-mediated eye-movements. Cognition. 2008; 108:896–904. [PubMed: 18692181]

Charman T, Drew A, Baird C, Baird G. Measuring early language development in preschool children with autism spectrum disorder using the MacArthur Communicative Development Inventory (Infant Form). Journal of Child Language. 2003; 30:213–236. [PubMed: 12718299]

Eberhardt, M.; Nadig, A. Reduced sensitivity to context in language comprehension: A characteristic of autism spectrum disorders or of poor structural language ability?. Research in Developmental Disabilities. 2016. http://dx.doi.org/10.1016/j.ridd.2016.01.017

Ellis Weismer S, Gernsbacher MA, Stronach S, Karasinski C, Eernisse E, Erickson C, Sindberg H. Lexical and grammatical skills in toddlers on the autism spectrum compared to late talking toddlers. Journal of Autism and Developmental Disorders. 2011; 41:1065–1075. [PubMed: 21061053]

Ellis Weismer S, Lord C, Esler A. Early language patterns of toddlers on the autism spectrum compared to toddlers with developmental delay. Journal of Autism and Developmental Disorders. 2010; 40:1259–1273. [PubMed: 20195735]

Fenson, L.; Marchman, V.; Thal, D.; Dale, P.; Reznick, JS.; Bates, E. MacArthur-Bates Communicative Development Inventories: Users guide and technical manual, Second Edition. Baltimore, MD: Brookes Publishing; 2007.

Fernald A, Marchman V. Individual differences in lexical processing at 18 months predict vocabulary growth in typically developing and late-talking toddlers. Child Development. 2012; 83:203–222. [PubMed: 22172209]

Fernald A, Perfors A, Marchman V. Picking up speed in understanding: Speech processing efficiency and vocabulary growth across the 2nd year. Developmental Psychology. 2006; 42:98–116. [PubMed: 16420121]

Fernald A, Pinto JP, Swingley D, Weinberg A, McRoberts G. Rapid gains in speed of verbal processing by infants in the 2nd year. Psychological Science. 1998; 9:228–231.

Fernald A, Swingley D, Pinto JP. When half a word is enough: Infants can recognize spoken words using partial phonetic information. Child Development. 2001; 72:1003–1015. [PubMed: 11480931]

Fernald, A.; Zangl, R.; Portillo, AL.; Marchman, V. Looking while listening: Using eye movements to monitor spoken language comprehension by infants and young children. In: Sekerina, IA.; Fernandez, EM.; Clahsen, H., editors. Developmental Psycholinguistics: On-line Methods in Children's Language Processing. John Benjamins; Amsterdam: 2008. p. 97-135.

Frith, U. Autism: Explaining the enigma. Oxford: Blackwell Publishing; 1989.

Hadad BS, Ziv Y. Strong bias towards analytic perception in ASD does not necessarily come at the price of impaired integration skills. Journal of Autism and Developmental Disorders. 2015; 45:1499–1512. [PubMed: 25518823]

Hahn N, Snedeker J, Rabagilati H. Rapid ambiguity resolution in young children with autism spectrum disorder: Eye tracking evidence for the limits of weak central coherence. Autism Research. 2015; 8:717–726. [PubMed: 25820816]

Hala S, Pexman P, Glenwright M. Priming the meaning of homographs in typically developing children and children with autism. Journal of Autism and Developmental Disorders. 2007; 37:329–340. [PubMed: 16855875]

Happé F, Booth R. The power of the positive: Revisiting weak coherence in autism spectrum disorders. Quarterly Journal of Experimental Psychology. 2008; 61:50–63.

Happé F, Frith U. The weak central coherence account: Detail-focused cognitive style in autism spectrum disorders. Journal of Autism and Developmental Disorders. 2006; 36:5–25. [PubMed: 16450045]

Henderson L, Clarke P, Snowling M. Accessing and selecting word meaning in autism spectrum disorder. Journal of Child Psychology and Psychiatry. 2011; 52:964–973. [PubMed: 21401594]

Henderson L, Powell A, Gaskell MG, Norbury C. Learning and consolidation of new spoken words in autism spectrum disorder. Developmental Science. 2014; 17:858–871. [PubMed: 24636285]

Houston-Price C, Mather E, Sakkalou E. Discrepancy between parental report of infants' receptive vocabulary and infants' behaviour in a preferential looking task. Journal of Child Language. 2007; 34:701–724. [PubMed: 18062356]

Huettig F, Altmann GTM. Word meaning and the control of eye fixation: Semantic competitor effects and the visual world paradigm. Cognition. 2005; 96:B23–B32. [PubMed: 15833303]

Hudry K, Ledbitter K, Temple K, Slonims V, McConahie H, Aldred C, Howlin P, Charman T. the PACT Consortium. Preschools with autism show greater impairment in receptive compared with expressive language abilities. International Journal of Language & Communication Disorders. 2010; 45:681–690. [PubMed: 20102259]

Järvinen-Pasley A, Wallace GL, Ramus F, Happé F, Heaton P. Enhanced perceptual processing of speech in autism. Developmental Science. 2008; 11:109–121. [PubMed: 18171373]

Jørgensen RN, Dale PS, Bleses D, Fenson L. CLEX: A cross-linguistic lexical norms database. Journal of Child Language. 2010; 37:419–428. [PubMed: 19570318]

Kaldy Z, Kraper C, Carter AS, Blaser E. Toddlers with Autism Spectrum Disorder are more successful at visual search than typically developing toddlers. Developmental Science. 2011; 14:980–988. [PubMed: 21884314]

Kamio Y, Robins D, Kelley E, Swainson B, Fein D. Atypical lexical/semantic processing in high-functioning autism spectrum disorders without early language delay. Journal of Autism and Developmental Disorders. 2007; 37:1116–1122. [PubMed: 17080275]

Kamio Y, Toichi M. Dual access to semantics in autism: Is pictorial access superior to verbal access? Journal of Child Psychology and Psychiatry. 2000; 41:859–867. [PubMed: 11079428]

López B, Leekam S. Do children with autism fail to process information in context? Journal of Child Psychology and Psychiatry. 2003; 44:285–300. [PubMed: 12587864]

Lord, C.; Luyster, R.; Gotham, K.; Guthrie, W. Autism Diagnostic Observation Schedule, Second Edition (ADOS-2) Manual (Part 2): Toddler Module. Torrence, CA: Western Psychological Services; 2012.

Lord, C.; Rutter, M.; DiLavore, PC.; Risi, S.; Gotham, K.; Bishop, S. Autism Diagnostic Observation Schedule, Second Edition (ADOS-2) Manual (Part 1): Modules 1–4. Torrence, CA: Western Psychological Services; 2012.

Mani N, Plunkett K. In the infant's mind's ear: Evidence for implicit naming in 18-month-olds. Psychological Science. 2010; 21:908–913. [PubMed: 20519485]

Mani N, Plunkett K. Phonological priming and cohort effects in toddlers. Cognition. 2011; 121:196–206. [PubMed: 21831366]

Mahr T, Macmillan B, Saffran J, Ellis Weismer S, Edwards J. Anticipatory coarticulation facilitates word recognition in toddlers. Cognition. 2015; 142:345–350. [PubMed: 26072992]

Marchman VA, Adams K, Loi E, Fernald A, Feldman HM. Early language processing efficiency predicts later receptive vocabulary outcomes in children born preterm. Child Neuropsychology. 2016; 17:649–665.

Marchman VA, Fernald A. Speed of word recognition and vocabulary knowledge in infancy predict cognitive and language outcomes in later childhood. Developmental Science. 2008; 11:F9–F16. [PubMed: 18466367]

Marslen-Wilson W, Zwitserlood P. Accessing spoken words: The importance of word onsets. Journal of Experimental Psychology: Human Perception and Performance. 1989; 15:576–585.

McMurray B, Samelson VM, Lee SH, Tomblin JB. Individual differences in online spoken word recognition: Implications for SLI. Cognitive Psychology. 2010; 60:1–39. [PubMed: 19836014]

Mirman, D. Growth Curve Analysis and Visualization Using R. Boca Raton, FL: CRC Press; 2014.

Norbury CF. Barking up the wrong tree? Lexical ambiguity resolution in children with language impairments and autism spectrum disorders. Journal of Experimental Child Psychology. 2005; 90:142–171. [PubMed: 15683860]

Norbury CF, Bishop DVM. Inferential processing and story recall in children with communication problems: A comparison of specific language impairment, pragmatic language impairment and high-functioning autism. International Journal of Language and Communication Disorders. 2002; 37:227–251. [PubMed: 12201976]

O'Riordan MA. Superior visual search in adults with autism. Autism. 2004; 8:229–248. [PubMed: 15358868]

Pellicano, E. Psychological models of autism: An overview. In: Roth, I.; Rezaie, P., editors. Researching the autism spectrum: Contemporary perspectives. New York, NY: Cambridge University Press; 2011. p. 219-265.

Plaisted K, O'Riordan M, Baron-Cohen S. Enhanced visual search for a conjunctive target in autism: a research note. Journal of Child Psychology and Psychiatry. 1998; 39:777–783. [PubMed: 9690940]

Ray-Subramanian C, Ellis Weismer S. Receptive and expressive language as predictors of restricted and repetitive behaviors in young children with autism spectrum disorders. Journal of Autism Developmental Disorders. 2012; 42:2113–2120. [PubMed: 22350337]

Riches N, Loucas T, Baird G, Charman T, Simonoff E. Elephants in pyjamas: Testing the weak central coherence account of autism spectrum disorders using a syntactic disambiguation task. Journal of Autism Developmental Disorders. 2016; 46:155–163. [PubMed: 26319252]

Robins, D.; Fein, D.; Barton, M. Modified Checklist for Autism in Toddlers (M-CHAT™. Storrs, CT: Self-published; 1999.

Rutter, M.; Bailey, A.; Lord, C. Social Communication Questionnaire. Los Angeles, CA: Western psychological Services; 2003.

Rutter, M.; Le Couteur, A.; Lord, C. Autism diagnostic interview-revised. Los Angeles, CA: Western Psychological Services; 2003.

Smith L, Yu C. Infants rapidly learn word-referent mappings via cross-situational statistics. Cognition. 2008; 106:1558–1568. [PubMed: 17692305]

Styles S, Plunkett K. How do infants build a semantic system? Language and Cognition. 2009; 1:1–24.

Swingley D, Pinto J, Fernald A. Continuous processing in word recognition at 24 months. Cognition. 1999; 71:73–108. [PubMed: 10444905]

Venker CE, Eernisse ER, Saffran JR, Ellis Weismer S. Individual differences in the real-time comprehension of children with ASD. Autism Research. 2013; 6:417–432. [PubMed: 23696214]

Volden J, Smith IM, Szatmari P, Bryson S, Fombonne E, Mirenda P, et al. Using the Preschool Language Scale, fourth edition to characterize language in preschoolers with autism spectrum disorders. American Journal of Speech-Language Pathology. 2011; 20:200–208. [PubMed: 21478278]

White S, Saldaña D. Performance of children with autism on the embedded figures test: A closer look at a popular task. Journal of Autism and Developmental Disorders. 2011; 41:1565–1572. [PubMed: 21350920]

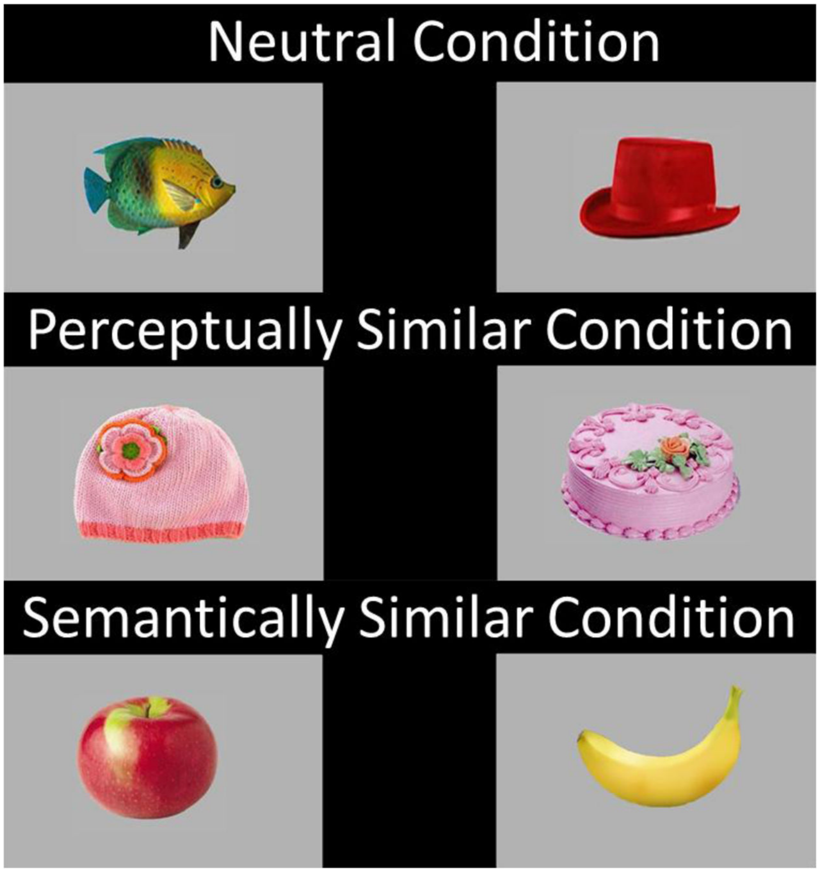

Figure 1.
Sample visual stimuli for the Neutral (Both Different) condition, Perceptually Similar (PS) condition, and Semantically Similar (SS) condition.

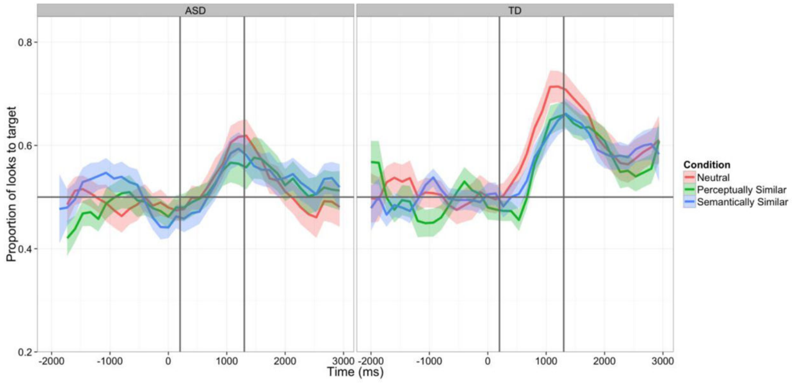

Figure 2.

Time course data for the ASD group (left panel) and TD group (right panel), averaged across trials and children. Error bars indicate +/− one standard error of the mean. The y-axis is mean accuracy (looks to target / looks to target and distractor). The x-axis is time in ms, with 0 indicating the onset of the target noun. The horizontal grey line indicates $y = .5$, which represents equal looking to target and distractor. Vertical grey lines indicate the test window (300ms to 2000ms after noun onset). Neutral condition data are in red, Perceptually Similar data are in green, and Semantically Similar data are in blue.

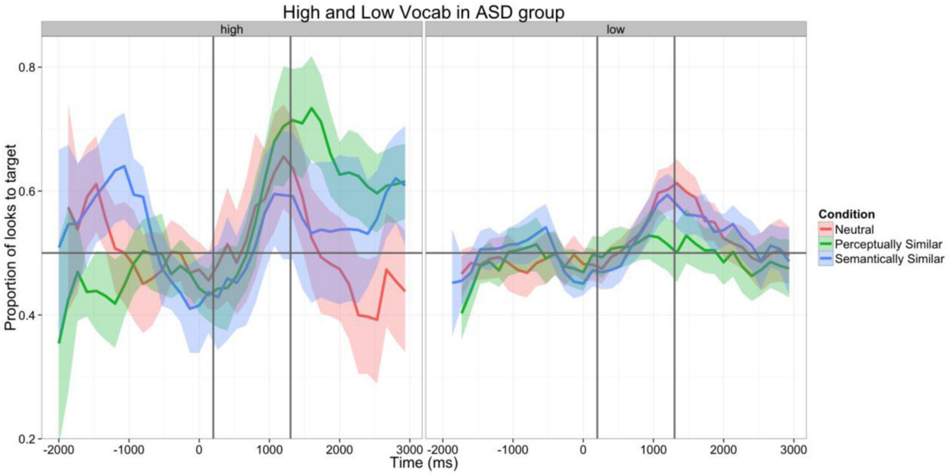

Figure 3.

Time course data for the ASD group with High Vocabulary (left panel) and Low Vocabulary (right panel), averaged across trials and children. Error bars indicate +/− one standard error of the mean. The y-axis is mean accuracy (looks to target / looks to target and distractor). The x-axis is time in ms, with 0 indicating the onset of the target noun. The horizontal grey line indicates $y = .5$, which represents equal looking to target and distractor. Vertical grey lines indicate the test window (300ms to 2000ms after noun onset). Neutral condition data are in red, Perceptually Similar data are in green, and Semantically Similar data are in blue.

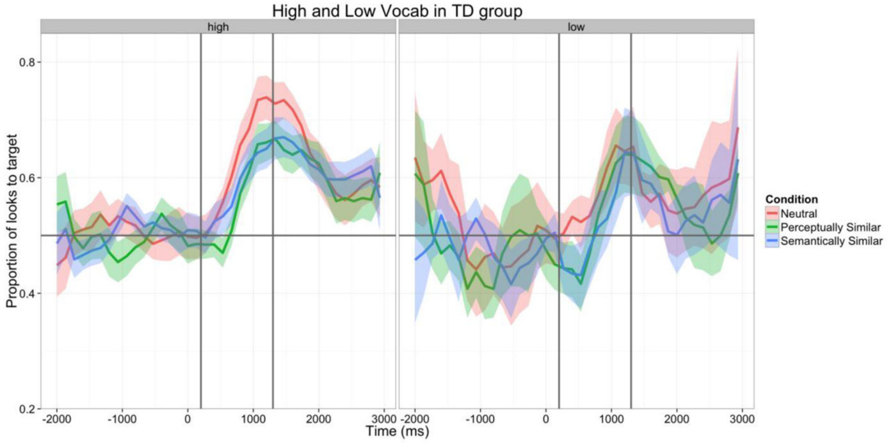

Figure 4.

Time course data for the TD group with High Vocabulary (left panel) and Low Vocabulary (right panel), averaged across trials and children. Error bars indicate +/− one standard error of the mean. The y-axis is mean accuracy (looks to target / looks to target and distractor). The x-axis is time in ms, with 0 indicating the onset of the target noun. The horizontal grey line indicates $y = .5$, which represents equal looking to target and distractor. Vertical grey lines indicate the test window (300ms to 2000ms after noun onset). Neutral condition data are in red, Perceptually Similar data are in green, and Semantically Similar data are in blue.

Table 1

Participant Characteristics

	TD (n = 30) ***M* (*SD*)** **Range**	**ASD (n = 30)** ***M* (*SD*)** **range**
Age in months*	20.87 (4.71) 14–29	30.57 (3.38) 24–36
Maternal education in years*	18.03 (2.98) 14–25	14.03 (1.90) 11–18
Bayley raw score	59.90 (9.03) 46–76	58.57 (10.11) 30–71
Bayley composite score*	106.17 (11.50) 90–130	80.83 (13.96) 55–105
Number of words understood *	278.13 (82.64) 122–394	140.20 (107.13) 0–395
Autism severity	-- --	8.10 (1.81) 4–10

Note.

*Group difference at $p < .05$. Bayley raw and composite scores were measured by the Bayley Scales of Infant Development. Number of words understood was measured by the Communicative Development Inventory (Words & Gestures form). Autism severity was measured by the Autism Diagnostic Observation Schedule-2 (ADOS-2) standardized calibrated severity scores.

Table 2

Verbal stimuli for the three conditions on the word recognition task

Neutral		Semantically Similar		Perceptually Similar	
Balloon	**Glasses**	**Cookie**	**Cheese**	**Shoe**	**Train**
Egg	Mouth	Apple	Banana	Bear	Table
Bear	Orange	Shoe	Sock	Moon	Banana
Shoe	Cracker	Dog	Fish	Ball	Cookie
Cake	Chair	Boot	Hat	Bike	Glasses
Frog	Clock	Fork	Plate	Spoon	Brush
Hat	Fish	Bear	Doll	Cake	Hat
Sock	Dog	Cup	Spoon	Plate	Orange
Ball	Nose	Frog	Duck	Cracker	Clock
Doll	Fork	Train	Bike	Egg	Balloon
Duck	Brush	Nose	Mouth	Cup	Apple
Slide	Cheese	Table	Chair	Slide	Boot

Note. Yoked pairs presented in the looking-while-listening task. Each image in a yoked pair served as both target and distracter.