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BRIEF REPORT

Brief Report: Early Lexical Comprehension in Young Children with ASD: Comparing Eye-Gaze Methodology and Parent Report

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Abstract Lexical comprehension is commonly measured by parent report, but it may be difficult for parents of children with ASD to accurately judge their child's comprehension. We compared parent report to an eye-gaze measure of lexical comprehension in which participants observed pairs of images on a screen, along with accompanying speech that named one of the two images. Twenty-two toddlers with ASD participated. Trials were included if the target word was reported as unknown. Children spent significantly more time looking at the target after it was named than before ($d = 0.66$). These results provide evidence that eye-gaze measures can reveal emerging lexical knowledge in young children with ASD that may otherwise be overlooked.

Keywords Assessment · Receptive vocabulary · Lexical comprehension · Parent report · Autism spectrum disorder

Introduction

One common approach for measuring early lexical comprehension is asking parents what words their child understands—for example, by using a checklist such as the MacArthur-Bates Communicative Development Inventory (CDI; Fenson et al. 2006). Parent report offers several advantages, including efficiency and ecological validity, and it is used extensively in clinical and research settings to assess word knowledge in children with and without ASD (Charman et al. 2003; Fenson et al. 1994; Heilmann et al. 2005; Luyster et al. 2007). However, concerns have been expressed about the accuracy of this approach (Tomasello and Mervis 1994; Yoder et al. 1997) because the CDI does not explain precisely how parents should gauge comprehension (Houston-Price et al. 2007; Tomasello and Mervis 1994). In addition, it may be particularly difficult to evaluate comprehension in children with ASD because their social impairments, limited spoken language, and atypical patterns of attention often lead to inconsistent and/or ambiguous responses. Because of these concerns, it is important to determine how parent report compares to other measures of lexical comprehension in children with ASD.

An alternative method for evaluating lexical comprehension in young children is measuring their eye movements in response to spoken language using an experimental eye-gaze method such as "looking-while-listening" (LWL; Fernald et al. 2008; also see Golinkoff et al. 2013). LWL presents two images on a screen, along with speech describing one of the images (e.g., *Find the hat*). Children are assumed to understand the target word when they look more at the named image than the unnamed image. Work with typically developing (TD) children suggests that eye-gaze methodology may provide a more sensitive measure of word comprehension than parent report (Houston-Price et al. 2007), but to our knowledge this question has not yet been addressed in children with ASD. This is an important issue to investigate because many young children with ASD have considerable delays

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in early language comprehension (Charman et al. 2003), and a critical step in understanding why these delays occur and how to treat them is ensuring that we measure comprehension accurately. The current study addressed this issue by testing whether LWL revealed emerging comprehension of words children were reported not to know. Based on findings in TD children (Styles and Plunkett 2009), we also tested whether comprehension of unknown words was lower when children were required to differentiate a named object from an object in the same taxonomic category (e.g., hat vs. boot)—a potentially more difficult task than differentiating unrelated objects (e.g., hat vs. fish).

LWL is a well-established measure of lexical comprehension in young TD children (Bergelson and Swingley 2012; Fernald et al. 2008), and a growing number of studies have used LWL or similar looking time measures with young children with ASD (Bavin et al. 2014; Brady et al. 2014; Goodwin et al. 2012; Venker et al. 2013). In one recent study, 3- to 6-year-olds with ASD demonstrated comprehension of known words in a LWL task, and accuracy was associated with their language abilities concurrently and 2 years earlier (Venker et al. 2013). However, it is not clear how children with ASD would perform in a LWL task when presented with words they are *not* reported to know. That is, will eye gaze in children with ASD provide evidence of more extensive lexical comprehension than is revealed by parent report?

In many ways, LWL represents a methodological complement to parent report, which makes it particularly useful to compare these measures. The CDI is subjective, relies on judgments made during natural social interactions, and requires children to have previously produced responses that indicate their understanding of particular words (e.g., pointing, labeling, following directions). In addition, the CDI has strong ecological validity because it is based on observations of children's behavior in everyday situations. However, natural environments present many distractions and thus may require the child to differentiate the referent of a word from many other options (e.g., a request to, "Find the ball" in a room full of toys). LWL, on the other hand, is objective, does not rely on social interaction, and requires no purposeful response from the child beyond looking and listening. LWL is a controlled experimental method, which limits its ecological validity. However, referent identification is relatively straightforward because children must differentiate a named image from only one other candidate referent.

Considering the differences between LWL and parent report, how might we expect these two methods to compare? Although no published studies have yet compared these methods in children with ASD, this issue has been investigated in young TD children. Using a looking time method similar to LWL, Houston-Price et al. (2007) found that TD infants (15–21 months) comprehended words that had been reported as unknown, suggesting that parents had underestimated their children's word knowledge (also see Bergelson and Swingley 2012; Fernald et al. 2006). Notably, Houston-Price and colleagues presented pairs of unrelated images (e.g., cup, hat), which may have allowed infants to identify the target words relatively easily. A study by Styles and Plunkett (2009) presented 18-month-old TD infants with image pairs from the same taxonomic category (e.g., dog, cat), thus increasing the difficulty of the task. Using this design, infants did *not* show comprehension of words reported as unknown (Styles and Plunkett 2009), suggesting that the alignment between parent report and eye-gaze methodology may depend on the relationship between the target and distracter images.

The Current Study

This study investigated the relationship between parent report and LWL for measuring understanding of object nouns in young children with ASD. Specifically, we asked: (1) In a LWL task, do young children with ASD understand words their parents report them *not* to know? (2) Does comprehension of 'unknown' words in the LWL task differ based on whether the image pairs were unrelated or from the same taxonomic category? We predicted that children with ASD would show evidence of comprehending 'unknown' words in the LWL task but that comprehension would be poorer when the image pairs were from the same category.

Methods

Participants were toddlers with ASD taking part in a study of lexical processing. The current study extends the original study by comparing LWL performance with parent report. Parents provided informed consent, and procedures were approved by the university Institutional Review Board. Families took part in a comprehensive, 2-day visit. An experienced psychologist provided a best estimate clinical DSM-5 diagnosis of ASD (American Psychiatric Association 2013) based on results of the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; Lord et al. 2012) and the Autism Diagnostic Interview, Revised or a toddler research version (Rutter et al. 2003). Of the full sample ($n = 32$), ten children were excluded because they were reported to know the majority of the target words. This left 22 participants (mean age = 30 months, SD = 3; 5 females) who contributed experimental data for at least four target words in each condition that had been reported as unknown. Children completed the Bayley Scales of Infant and Toddler Development, Third Edition (Bayley 2006), and parents completed the CDI Words and Gestures form (Fenson et al. 2006). Mean Bayley cognitive composite was 77 (SD = 14), and mean autism severity score on the ADOS-2 was 9 (SD = 2). On average, children were reported to understand 91 words (SD = 70) and produce 15 words (SD = 19).

In the LWL task, visual stimuli were presented on a 55-inch screen, and auditory stimuli were presented at approximately 63 dB. Children sat on a parent's lap 60 inches from the screen. Parents wore blacked-out sunglasses so that they did not unintentionally influence children's performance. A video camera recorded children's faces for offline coding. In each trial, children saw two images, one of which was named (e.g., *Find the sock*). The task included three conditions that were interspersed with one another. One condition presented visually similar images; this condition was not analyzed because there was no theoretical motivation for investigating alignment with parent report in these trials. In the Related condition, image pairs were taxonomically related (e.g., apple, banana). In the Unrelated condition, image pairs were unrelated (e.g., cracker, shoe).

Children participated in the LWL task on both days. On each day, they viewed 12 trials per condition, yielding a maximum of 24 per condition. Each trial within a condition presented a different target word. Image pairs were yoked within each condition; each item in a pair that had served as the target on the first day, served as the distracter on the second day (see Table 1). For the "sock/dog" pairing, for example, "sock" served as the target on the first day and "dog" served as the target on the second day. Condition and target side were counterbalanced. Only trials that had been reported as unknown on the CDI (i.e., the child was not reported to understand, or understand and say the word) were retained for the analyses. Two versions of the task were used that presented trials in a different order; there were no significant differences between the versions, $p = .48$, so data were collapsed.

Children's eye movements were coded from video by trained research assistants at a standard rate of 30 frames per second, producing time frames that lasted approximately 33 ms. Following standard coding procedures (Fernald et al. 2008), each frame was assigned a single code of 'target' or 'distractor,' depending on which image the child was looking at; children had time to fixate only one of the images during each frame. Frames in which children were not looking at either image (i.e., shifts between images, looks away from the screen) were removed. The dependent variable was the proportion of looks to target, which was calculated by dividing the number of frames with a target look by the number of frames with a look to either image. For example, if a child looked at the target for 35 frames and the distracter for 5 frames during the test window, the proportion of looks to target would be 88 % (35/40). Proportion of looks to target was calculated during two time windows: baseline (the 2000 ms before noun onset; 61 frames) and test (300–2000 ms after noun onset; 52 frames). During baseline, children were expected to spend a roughly equal amount of time looking at each image (i.e., the proportion of looks to target would be approximately 50 %) because neither image had yet been named. During the test window, children were expected to look more at the named image if they understood the target word.

Trials were excluded if children looked away from the images during more than half of the test window. This resulted in a mean loss of 3.23 trials per child in the Unrelated condition (SD = 3.37, range = 0–12) and 3.86 trials per child in the Related condition (SD = 3.85, range = 0–13). Because this study focused on unknown words, trials were also excluded if the child was reported to know the target word. This resulted in a mean loss of 7.09 trials in the Unrelated condition (SD = 5.70, range = 0–18) and a mean loss of 7.00 trials in the Related condition (SD = 5.77, range = 0–20). The mean number of trials contributed by each of the 22 children was 11.86 (of a maximum of 24) in the Unrelated condition (SD = 4.59, range = 4–20) and 11.36 (of a maximum of 24) in the Related condition (SD = 5.25, range = 4–20). In the analyzed trials, we calculated the mean proportion of time children looked at either the target or distractor image; the remaining proportion of time represented looks that were not directed to either image. In the Unrelated condition, children looked at the images 83 % of the time during the baseline window (SD = 6 %) and 90 % of the time during the test window (SD = 5 %). In the Related condition, children looked at the images 82 % of the time during the baseline window (SD = 6 %) and 90 % of the time during the test window (SD = 5 %).

Results

Time course data are presented in Fig. 1 and mean proportion of looks to target is presented in Fig. 2. The mean proportion of looks to target in the Unrelated condition was 51.17 % during baseline (SD = 6.87 %, range = 40.69–63.61) and 54.24 % during the test window (SD = 11.42 %, range = 27.89–81.78). The mean proportion of looks to target in the Related condition was 49.99 % during baseline (SD = 6.55 %, range = 36.40–62.95) and 55.05 % during the test window (SD = 8.83 %, range = 40.10–73.86). Our first question was whether, in the LWL task, children showed comprehension of words their parents had reported them not

Table 1 Looking-while-listening stimuli

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

Yoked pairs presented in the Unrelated and Related conditions. Each image in a yoked pair served as both target and distracter. Words presented in both conditions (using different images) are bolded

to know. Our second question was whether comprehension of 'unknown' words in the LWL task differed based on whether the image pairs were unrelated or were from the same taxonomic category. We addressed these questions by conducting an ANOVA with proportion of looks to target as the dependent variable, and Window (baseline vs. test), Condition (Unrelated vs. Related), and the Window*Condition interaction as independent variables. There was a main effect of Window, $F(1, 84) = 4.86$, $p = .03$, $\eta_p^2 = .050$, indicating that children looked significantly more at the target after it was named. The standardized mean difference between baseline and test window was $d = 0.33$ for the Unrelated condition and $d = 0.65$ for the Related condition. There was no significant main effect of Condition, $F(1, 84) = 0.01$, $p = .92$, $\eta_p^2 = .0001$, nor a Window*Condition interaction, $F(1, 84) = 0.29$, $p = .59$, $\eta_p^2 = .003$.[1] Because the main effect of Condition was not significant, we conducted the ANOVA collapsing across conditions. The mean proportion of looks to target was 50.69 % at baseline (SD = 4.10 %, range = 40.20–61.84) and 54.52 % during the test window (SD = 7.15 %, range = 45.29–68.95). The main effect of Window remained significant, $F(1,42) = 4.76$, $p = .03$, $\eta_p^2 = .102$. The standardized mean difference between baseline and test window after collapsing across conditions was $d = 0.66$.

[1] Although the primary purpose of this study was to investigate comprehension at the group level, we also calculated correlations between the total number of words each child was reported to understand, and the child's mean proportion of looks to target during the test window in each condition. Correlations for the full group ($n = 22$) were non-significant for the Unrelated condition ($r = -.02$, $p = .93$) and the Related condition ($r = .23$, $p = .30$). Based on a reviewer suggestion, we also calculated these correlations for the subgroup of children whose performance was within or above the 95 % confidence interval of the group mean in each condition. The correlations ($n = 15$) remained non-significant for the Unrelated condition ($r = -.12$, $p = .68$) and for the Related condition ($r = .31$, $p = .26$).

Discussion

To our knowledge, this is the first study to compare lexical comprehension in young children with ASD measured by both looking-while-listening (LWL) and parent report. Consistent with work in typically developing children (Bergelson and Swingley 2012; Houston-Price et al. 2007), children with ASD demonstrated understanding of nouns in a LWL task that their parents had reported them not to know. These results suggest that children with ASD have an emerging understanding of certain words, even if they do not yet consistently demonstrate this knowledge to their parents. This is an important finding because it provides evidence that LWL—a sensitive, implicit measure that monitors children's eye movements as they listen to spoken language—can reveal lexical knowledge in young children with ASD that may otherwise be overlooked. Although children did not show a large increase in proportion of looking to target after the target image was named (i.e., a change from approximately 50–55 %, $d = 0.66$), their performance is generally consistent with previous studies of young typically developing children (Houston-Price et al. 2007; Styles and Plunkett 2009).

It was interesting that children showed comprehension of 'unknown' words regardless of whether the image pairs were taxonomically related or unrelated. This is inconsistent with Styles and Plunkett's (2009) finding that TD children did *not* show comprehension of unknown words in a LWL task when the distracters were taxonomically similar. However, it is possible that lexical knowledge is organized differently in children with ASD (Dunn et al. 1996; Kamio et al. 2007), and as a result their processing was not as affected by taxonomic similarity. Alternatively, this finding could be explained by methodological differences between our study and the study by Styles and Plunkett (e.g., participant ages, number of trials, specific images presented). Future studies using a comparison group of typically developing children may help to address this issue.

Why did LWL provide a more sensitive measure of lexical comprehension than parent report? As discussed, there are several factors that may help to explain this finding. Accurately gauging a child's understanding of specific words may be quite challenging for parents (Yoder et al. 1997), especially when the child has ASD. The CDI asks parents to judge word knowledge by comparing children's behaviors against an internal threshold, but it

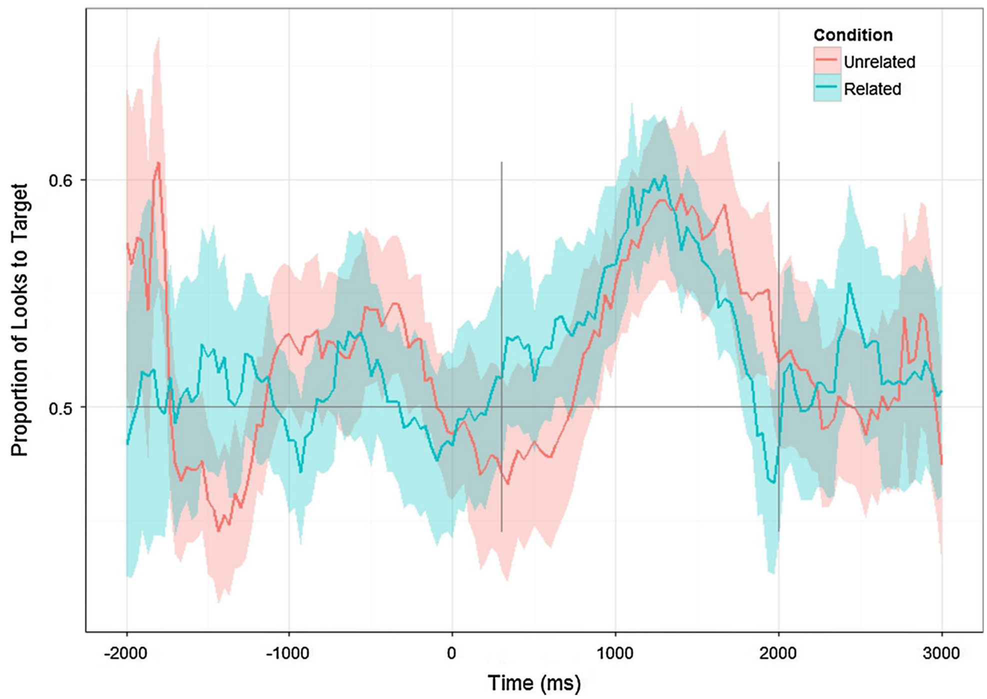

Fig. 1 Time course data averaged across trials and children. Shading indicates ± one standard error of the mean. The y-axis is mean proportion of looks to target (looks to target/looks to target and distracter). The x-axis is time in ms, with 0 indicating the onset of the target noun. The *horizontal grey line* indicates $y = .5$, which represents equal looking to target and distracter. The *grey vertical lines* indicate the test window (300–2000 ms after noun onset) (Color figure online)

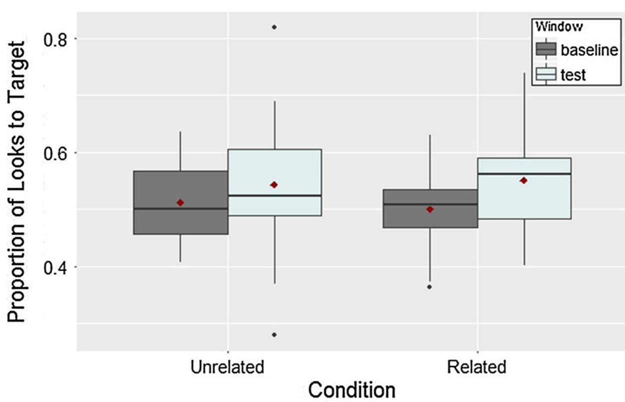

Fig. 2 Plot of proportion of looks to target (looks to target/looks to target and distracter) by window and condition. The *solid center lines* indicate the median. The *diamonds* indicate the mean. The *upper* and *lower* hinges represent the 25th and 75th percentiles. The upper whiskers extend from the hinge to the highest value within 1.5*interquartile range (IQR), where IQR is the distance between the first and third quartiles. The lower whiskers extend from the hinge to the lowest value within 1.5*IQR of the hinge. The data points beyond the whiskers fall outside of this range and thus may be considered outliers. The baseline window was the 2000 ms prior to noun onset. The test window was 300–2000 ms after noun onset. There was a main effect of window, with significantly greater mean proportion of looks to target in the test window, regardless of condition

provides no specific instructions about what this threshold should be (Houston-Price et al. 2007; Styles and Plunkett 2009; Tomasello and Mervis 1994). Additionally, natural environments present children with many things to see and hear, which may make it more difficult to interpret children's behaviors with certainty. LWL, on the other hand, is objective, non-social, has limited behavioral task demands, and only requires children to differentiate a named object from one other potential referent—factors that may converge to reveal emerging lexical knowledge.

Furthermore, the CDI only allows parents to indicate whether a child does or does not understand a word—a dichotomous response. LWL, on the other hand, measures comprehension on a continuous scale (i.e., proportion of looking to target). Because children's understanding of even a single word develops considerably over time (Fernald et al. 2006), measures that provide a range of responses may in some cases be better suited for assessing emerging lexical comprehension. One way to increase the sensitivity of parent report may be to develop rating scales that allow parents to indicate not only whether their child knows a word, but also how well (Houston-Price et al. 2007). In addition, it may be useful to provide parents with instructions on how to set a threshold for gauging comprehension when using the traditional measure (Houston-Price et al. 2007; Styles and Plunkett 2009).

Regardless of how children perform in lab-based experimental tasks, parent report measures will continue to be a valuable clinical and research tool because they provide information about parents' perceptions of their children's lexical knowledge. Following the transactional account of language development (Sameroff and Fiese 2000), a parent's sense of what words her child understands plays a critical role in language development; believing that a child does not understand a particular word shapes what a parent says and how she says it. For this reason, it is important for parents, clinicians and researchers to be aware that young children with ASD may have emerging knowledge of certain words, even if they do not yet demonstrate this knowledge in consistent and/or interpretable ways.

The primary limitation of this study was that the target words were categorized as 'unknown' per parent report after the data had been collected. For this reason, ten participants with ASD were excluded because they knew too many of the words in the LWL task, which limited the generalizability of our results. In addition, trials with 'known' targets were excluded, which limited the number of trials contributed by each child. Furthermore, we were unable to include data from the comparison group of TD children who also took part in this study because they were reported to know many of the target words. We were also unable to statistically analyze the role of distracter knowledge because the number of trials was quite limited when we created subgroups of trials in this way. Knowing about both targets and distracters is advantageous because mutual exclusivity may play a role in how children comprehend spoken words in experimental looking time tasks (Houston-Price et al. 2007; Styles and Plunkett 2009). Tailoring the experimental stimuli to individual children's vocabularies (Houston-Price et al. 2007) in future work may increase participant inclusion and allow researchers to investigate the role of distracter knowledge. Such studies may also determine whether LWL accuracy is higher for words that children with ASD *know* than for words they are reported *not* to know, which should be a priority for future research.

Our results suggest that LWL provided a more sensitive measure of early noun comprehension in toddlers with ASD than parent report, but it is important to remember that all comprehension measures have both strengths and limitations. For example, even though children in this study looked significantly longer at the target image in the LWL task after it was named, we do not yet know how comprehension that is apparent in LWL tasks relates to how children understand language in their everyday lives. Although there was evidence of comprehension in the LWL task at the group level, there was also considerable within-group heterogeneity, with mean proportion of looks to target during the test window ranging from 30 to 80 % across individual participants. This confirms what we know about variability in language skills in young children with ASD and suggests that participants showed emerging lexical comprehension of 'unknown' words to varying degrees. Further methodological comparisons are needed to advance our understanding of early lexical comprehension in children with ASD. It is important that we continue to approach this issue with the goal not of identifying which measure is best, but of learning what each measure can tell us and what it cannot.

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

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