Published in final edited form as:

J Autism Dev Disord. 2019 August ; 49(8): 3351–3363. doi:10.1007/s10803-019-04054-5.

Specificity of Phonological Representations for Children with Autism Spectrum Disorder

Ron Pomper[1,2], **Susan Ellis Weismer**[2,3], **Jenny Saffran**[1,2], **Jan Edwards**[4]

[1]Department of Psychology, University of Wisconsin-Madison, Brogden Hall, 1202 West Johnson Street, Madison, WI 53706, USA

[2]Waisman Center, University of Wisconsin-Madison, 1500 Highland Avenue, Madison WI 53705, USA

[3]Department of Communication Sciences and Disorders, University of Wisconsin-Madison, Goodnight Hall, 1975 Willow Drive, Madison, WI 53706, USA

[4]Department of Hearing and Speech Sciences, University of Maryland, Samuel J. LeFrak Hall, 7521 Preinkert Drive, College Park, MD 20742

Abstract

This study investigated whether children with autism spectrum disorder (ASD) are sensitive to mispronunciations of familiar words and compared their sensitivity to children with typical-development. Sixty-four toddlers with ASD and 31 younger, typical controls participated in a looking-while-listening task that measured their accuracy in fixating the correct object when it was labelled with a correct pronunciation versus mispronunciation. A cognitive style that prioritizes processing local, rather than global features, as claimed by the weak central coherence (WCC) theory, predicts that children with ASD should be more sensitive to mispronunciations than typical controls. The results, however, reveal no differences in the effect of mispronunciations on lexical processing between groups, even when matched for receptive language or nonverbal cognitive skills.

Many young children with autism spectrum disorder (ASD) are delayed in language acquisition. While problems in social communication are central to the diagnosis of autism, the extent of delays in structural language (i.e., semantics, syntax, morphology, phonology) varies dramatically across children and is associated with long-term outcomes (Kjelgaard & Tager-Flusberg, 2001; Pickles, Anderson, & Lord, 2014; Tager-Flusberg & Kasari, 2013). The mechanisms underlying impairments in language acquisition for children with ASD are poorly understood. Much of the research focused on identifying the mechanisms underlying language impairments in ASD has examined social factors, like children’s ability to follow a

Corresponding Author: Ron Pomper rpomper@wisc.edu.

Conflict of interest: The authors declare that they have no conflict of interest.

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 and comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

speaker's gaze (Baron-Cohen, Baldwin, & Crowson, 1997; McDuffie, Yoder, & Stone, 2006; Norbury, Griffiths, & Nation, 2010), their ability to establish joint attention (Mundy, Sigman, Ungerer & Sherman, 1986; Osterling & Dawson, 1994), social orienting in response to one's name (Dawson et al., 1998; Dawson et al., 2004; Osterling & Dawson, 1994; Osterling, Dawson & Munson, 2002; Werner, Dawson, Osterling & Dinno, 2000), and lack of social interest in communication and specifically speech (Baron-Cohen, Tager-Flusberg & Cohen, 1993; Kuhl, Coffey-Corina, Padden, & Dawson, 2005). In addition to social factors, however, differences in cognitive/perceptual strengths and weaknesses for children with ASD may also affect the mechanisms of language acquisition and underlie impairments in language development.

A number of different cognitive/perceptual theories have been proposed to account for the autism phenotype (see Brown & Bebko, 2012 and Pellicano, 2011). For the purpose of this investigation, we focus on one theory that has generated a considerable amount of research exploring autism symptoms broadly as well as specifically examining language abilities in ASD. Weak Central Coherence (WCC) proposes that individuals with autism have an attentional style or bias to process information at the local, rather than global level (Happé & Booth, 2008; Happé & Frith, 2006). Thus, individuals with autism focus on fine-grained detail and have difficulty integrating information with the surrounding context. Substantive modifications of the original theory (Frith, 1989) have been proposed (Happé & Booth, 2008; Happé & Frith, 2006), as well as alternative explanations focused on enhanced perceptual processing along with secondary effects on higher-level conceptual processing (Iarocci, Burack, Shore, Mottron, & Enns, 2006; Mottron & Burack, 2001; Mottron, Burack, Iarocci, Bellevile, & Enns, 2003; Plaisted, 2000; Plaisted, 2001). There has been debate within the literature regarding the extent to which problems with central coherence can be conceptualized as a deficit in executive function related to difficulties in shifting between local and global levels of processing (Booth, Charlton, Hughes, & Happé, 2003; Hala, Pexman, & Glenwright, 2007), but longitudinal research by Pellicano (2010, 2011) has failed to find a developmental association between executive function and central coherence in children with ASD. From the perspective of the WCC account, perceptual differences result in improved performance on many perceptual tasks but may also cause deficits in tasks that require using context to see the big picture. In particular, individuals with ASD may process perceptual information veridically, which may interfere with their ability to perceive perceptual information categorically.

With regard to perceptual processing, some children with ASD excel at visual and auditory tasks that privilege local processing. Children with ASD perform better in difficult visual search tasks than typically developing (TD) peers who are matched on both age and either verbal or nonverbal developmental level (Plaisted, O'Riordan & Baron-Cohen, 1998; O'Riordan, Plaisted, Driver & Baron-Cohen, 2001). Moreover, children with ASD are faster in finding geometric shapes embedded within complex figures and reconstructing geometric patterns by combining different blocks than TD peers who are matched on age or on nonverbal developmental level (Shah & Frith, 1983; 1993). In the auditory domain, children with ASD are better at discriminating changes in phonological features that are *not* part of their native language compared to TD peers who are matched in age (DePape, et al., 2012; You, Serniclaes, Rider, & Chabane, 2017).

A bias to process auditory information at the local level, however, may be detrimental to children's language development, which requires some level of abstraction at the global level (e.g., recognizing the word 'cow' despite differences in speakers' voices, background noise, disfluencies). Despite their superior performance on many auditory discrimination tasks, children with ASD are worse at discriminating changes in phonological features of their native language compared to TD peers who are matched in age (Ceponiene et al., 2003; Jansson-Verkasalo et al., 2003; Oram Cardy et al., 2005), nonverbal (Key, Yoder, & Stone, 2016; Kuhl et al., 2005), and verbal developmental level (You, Serniclaes, Rider, & Chabane, 2017; cf. Constantino et al., 2007; Kemner et al., 1995, Lepistö et al., 2005). Thus, children with ASD may have reduced re-organization of their perception around categorical prototypes (i.e., phonemes) and instead process auditory information more veridically. These differences in processing auditory speech may have downstream consequences for children's language acquisition: children with autism who have weaker phoneme discrimination fail to show a preference for speech over non-speech stimuli and have greater disparities between their nonverbal and verbal IQ (Key, Yoder, & Stone, 2016; Kuhl et al., 2005).

It is important to note that the research examining phonological processing in children with ASD described above has focused on the syllable level. When acquiring language, however, children are not perceiving phonemes in isolated syllables, but rather phonemes embedded in words in a continuous stream of speech. Contrary to their poorer performance in detecting changes in phonemes in isolation, some individuals with ASD outperform their TD peers in detecting changes in phonemes embedded in words. Children with ASD recall more phonological detail of newly-learned words than their TD peers who are matched in age, nonverbal, and verbal developmental level (Norbury et al., 2010). Unlike TD peers who are matched in age and verbal ability, children with ASD show immediate effects of lexical competition from newly-learned words (Henderson, Powell, Gaskell, & Norbury, 2014). Neurotypical adults with more autistic traits are less likely to have their perception of ambiguous phonemes affected by lexical context (Stewart & Ota, 2008). Consistent with WCC, these results suggest that individuals with ASD may be biased to perceive phonemes locally (e.g., /g/ vs. /k/), without their perception biased by their knowledge of words vs. non-words (e.g., *kiss* is a word, but *giss* is not). This research, however, has involved older children (between the ages of 6 to 7) and adults who were matched in verbal ability to their TD peers. Our research fills an important empirical gap by examining how younger children with ASD process phonological information embedded within familiar words. Moreover, we will examine this in children with ASD who are vs. are not matched to TD peers in verbal ability. This last comparison is particularly important, because prior research suggests that children with ASD who have language impairments are also impaired in phonological processing (Lindgren, Folstein, Tomblin, & Tager-Flusberg, 2009; Loucas et al., 2008).

There is a large literature of research examining how young, typically-developing children process phonological information in familiar words. Contrary to early hypotheses that children's representations of words were imprecise and gradually became more detailed with development (Charles-Luce & Luce, 1990; Jusczyk, 1993; Metsala & Walley, 1998), recent research suggests that early in development, children have detailed representations of words. Infants as young as 11 months of age discriminate between correct pronunciations and mispronunciations of familiar words (Swingley, 2005). Studies examining the precision of children's familiar word representations frequently use a mispronunciation paradigm (Swingley & Aslin, 2002). In this task, children first see a pair of images depicting objects with known names. They then hear a sentence labeling the target object using either a correct pronunciation (e.g., 'Find the baby) or mispronunciation (e.g., 'Find the vaby). By tracking children's eye movements, past research has found that children are significantly less accurate in fixating the target object on mispronunciation compared to correct pronunciation trials (e.g., Swingley & Aslin, 2002). These data suggest that neurotypical children represent the sounds of words with sufficient specificity that they do not confuse "vaby" for "baby".

In the current experiment, we used this mispronunciation paradigm to assess auditory perception at the word level for children with ASD. Based on the WCC theory and past research in which children with ASD outperform their TD peers in encoding phonological information of newly-learned words (Henderson et al., 2010; Norbury et al., 2010), we predicted that children with ASD would be *better* than children with TD at discriminating fine phonetic differences in familiar words and less likely to have their perception biased by global information (i.e., lexical knowledge). Therefore, children with ASD should be *more* affected by mispronunciations (i.e., experience a greater decrease in their accuracy in fixating the target object) compared to their TD peers. The extent to which global information affects local processing depends on the strength of children's lexical knowledge. Because children with ASD, as a group, have weaker receptive language skills than their TD peers, we also tested our hypothesis with a subsample of children who were matched in receptive language skills to account for this potential confound.

Method

Participants

The final sample included 64 children with ASD (24-36 months; 17 females) and 31 younger children with TD (18-24 months; 13 females). This difference in age was intentional and was necessary to reduce the disparity in receptive language skills between both groups. Children in the ASD group were recruited through early intervention programs, doctors' offices, and a research registry for individuals with developmental disabilities. Children with uncorrected hearing or vision impairments, known chromosomal abnormalities, cerebral palsy, fetal alcohol syndrome, seizure disorders, or other neurological disorders were excluded. Children in the TD group were excluded if there were signs of developmental delay per parent report on the background information form (described below), if the child scored more than one SD below the mean on assessment measures of language or nonverbal cognition, or if the child was at an increased risk for ASD based on an autism screening test. For the ASD Group, an additional 12 children were tested but not included in the final sample because they did not meet diagnostic criteria for ASD (n=4), did not meet exclusionary criteria (n=3), failed to return for the second day of testing (n=1), or had too much missing data (n=4; i.e., fewer than 6 useable trials in one or both conditions). For the TD Group, an additional 14 children were tested but not included in the final sample due to developmental delay (n=6), language impairment (n=4), or suspected ASD (n=4).

Procedure

Participation involved two visits that were scheduled no more than 3 weeks apart. Each visit lasted approximately 2.5 hours for children with ASD and 1 hour for children with typical development (TD). All children completed multiple looking-while-listening (LWL; Fernald et al., 2008) tasks during each session, as well as assessments of verbal and nonverbal cognitive ability; the other experimental eye-gaze tasks are reported elsewhere (Ellis Wesimer et al. 2016; Mahr et al. 2015; Venker et al. 2016, 2019). In addition, children with ASD completed an autism assessment. Parents completed several questionnaires providing background information and assessing their child's vocabulary.

Assessment Measures

Parents completed a written questionnaire providing information about their child's medical and treatment history. Parents of TD children completed the Modified Checklist for Autism in Children (M-CHAT; Robins et al., 2001). None of the scores for the TD children in the final sample met the cutoff for concerns regarding ASD. Children in the ASD group completed the *Autism Diagnostic Observation Schedule, 2nd Edition* (ADOS-2; Lord et al., 2012) and parents of children in the ASD group completed *Autism Diagnostic Interview, Revised* (ADIR; Rutter et al., 2003). Children either received Module 1 or 2 or the Toddler Module based on their age and language level. An experienced psychologist administered both tasks. DSM-5 criteria were used to make a best estimate clinical diagnosis (American Psychiatric Association, 2013). All children completed the Preschool Language Scales, 4th edition (PLS-4; Zimmerman, Steiner & Pond, 2002). In addition, all parents completed the MacArthur-Bates Communicative Development Inventories (MB-CDI; Words and Sentences Form; Fenson et al., 2007). Children's Auditory Comprehension score (PLS-4) and the number of words that they were reported to understand (MB-CDI) were used to assess their language comprehension. We used measures of receptive language, rather than expressive language, because our experimental task involves comprehension (see next section). We found the same pattern of results for both of our measures of language ability; we therefore report our analyses using PLS-4 and have included the results using MB-CDI scores in the Supplementary Material. Finally, all children completed the Mullen Scales of Early Learning (Mullen, 1995). Children's score on the Visual Reception scale was used as a measure of their nonverbal cognitive ability.

Experimental Task

Mispronunciation Paradigm—The specificity of children's phonological representations was assessed using Swingley and Aslin's (2002) mispronunciation paradigm. This paradigm uses a LWL task to measure children's lexical processing (Fernald et al., 2008). Children were seated on their caregiver's lap approximately 2 feet away from a 55-inch LCD screen with a speaker mounted underneath. Caregivers wore opaque sunglasses to prevent them from seeing visual stimuli and were instructed to not repeat any of the words or point to the screen. On each trial, children were shown pictures of two familiar objects on the screen. The pictures were displayed in silence for 1.5 seconds. Children then heard a sentence labelling one object. On 24 trials, the target object was labelled using a Correct Pronunciation (CP; e.g., *Find the cow*). On 24 other trials, the target object was labelled using a Mispronunciation (MP; e.g., *Find the gow*). See Supplementary Material for a list of all labels and their mispronunciations. Trials were divided into two blocks and children completed one block of trials on each visit. Children's eye movements were recorded by video camera and coded offline (see below).

Trial Order—Twelve familiar objects were yoked into pairs such that the same two objects were always presented together (e.g., *cow* and *shirt* always occurred on the same trial). Each yoked pair was phonologically dissimilar (i.e., different initial consonants and no rhymes) and semantically dissimilar (e.g., no two animals were yoked together). Each yoked pair occurred on 8 trials (for a total of 48 trials). Within each yoked pair, each object occurred equally often as the target and as the distractor on the right and left side of the screen, and in each condition (CP vs. MP). Trials were divided equally into two blocks that were administered during separate visits. Within each block, trials were arranged in pseudorandom order such that children saw all 6 yoked pairs before a given yoked pair was repeated and the target object did not occur on the same side for more than two consecutive trials.

Visual Stimuli—Color photographs depicting each familiar object were found online by searching an image database. Photographs were selected to be prototypical exemplars that would be familiar to children. Because each object was used on multiple trials, we selected four different images of each object to help maintain children's interest and attention. All pictures were edited using Photoshop so that objects were approximately the same size. Each object was presented on a gray background to enhance visibility. On each trial, one picture was displayed in the bottom left corner of the large television screen and another picture was displayed in the bottom right corner.

Auditory Stimuli—The objects were chosen so that their labels would be highly familiar to children in our experiment. We used Wordbank — a database with information on vocabulary development based on CDI norms for TD children — to validate the familiarity of the labels (http://wordbank.stanford.edu). On average, 86% of typically-developing 18-month-old children are reported to comprehend the labels for the objects in our stimuli (see Supplementary Material for a list with comprehension norms for each label). The auditory stimuli on each trial consisted of two sentences. The first sentence labelled the target object using a carrier phrase with the label in the final position (e.g., "Find the cow."). The second sentence was included to maintain children's attention (e.g., "Do you see it?"). There was 600 ms of silence between sentences. A female, native English speaker with a local Midwestern accent recorded multiple tokens for each sentence. Tokens were chosen to have similar intonation contours and were edited using Praat to normalize across items for both intensity (RMS amplitude) and duration.

Data Coding and Cleaning—Children's fixations were video recorded and coded offline by trained coders who were blind to the target object, target location, and condition. Using custom software, coders indicated in 33 ms increments whether children were looking at the left picture, right picture, shifting between pictures, or looking away (Fernald et al., 2008). To determine reliability, 20% of children in each group (14 for the ASD Group and 7 for the

TD Group) were randomly selected and both videos (i.e., one from each session) were coded independently by two coders. Initially, 81% of trials for the ASD Group and 79% of trials for the TD Group were comparable (a trial is only comparable when both coders recorded the same number of looks for that trial). Trials that were not initially comparable were discussed and consensus coded.[1] We then quantified inter-coder agreement using two measures: (a) the proportion of all frames on which coders agreed on the fixation location and (b) the mean proportion of shifts in fixations on which coders agreed within one frame. For the ASD group, frame agreement was 99% and shift agreement was 98%. For the TD group, frame agreement was 98% and shift agreement was 95%.

Based on prior research, we set our window of analysis to be 300 to 1800 ms after the onset of the target word (Fernald et al., 2008). Fixations before the window are unlikely to be stimulus-driven (i.e., in response to the target word), because it takes children approximately 300 ms to program an eye movement. Fixations after the window are also less likely to be stimulus-driven, because children's attention wanes over time. Trials in which children looked at the pictures for less than half of the critical window were excluded because they did not include adequate data. Out of the possible 24 trials per condition, children in the TD Group contributed an average of 20.7 trials (SD = 3.9) in the CP condition and 20.8 trials (SD = 3.9) in the MP condition. Children in the ASD Group contributed an average of 18.1 trials (SD = 5.0) in the CP condition and 18.6 trials (SD = 4.8) in the MP condition. Children in the ASD Group had significantly fewer useable trials compared to children in the TD group, $b = -2.4$, $F(1,93) = 6.1$, $p < .02$. This was expected based on prior eye-tracking research comparing lexical processing in TD and ASD children (Ellis Weismer et al. 2016). Children had the same number of useable trials across the two conditions and this did not differ between Groups, p's > .10.

Statistical Analyses—We used mixed-effects growth curve analysis (GCA) to quantify changes in the time course of children's fixations during the critical window (Mirman, 2016). The dependent variable was the proportion of trials on which children were fixating the target object out of the trials they were fixating the distractor object, calculated for each frame (i.e., every 33 ms). This proportion was transformed to empirical log-odds in order to accommodate the binary nature of the data (i.e., fixations were either to the target or to the distractor). We used the following orthogonal polynomials to quantify changes in the time course of children's fixations: intercept, linear, quadratic, and cubic time terms. The intercept was centered and reflects the average fixation proportion across the critical window (this is analogous to calculating children's average accuracy). Linear time captures the monotonic change in fixation proportion (i.e., the average slope of the line). Quadratic time captures the rate of the symmetric rise and fall around the peak asymptote in fixation proportions. Cubic time captures the slope of the tails. The cubic time term quantifies any delay in increasing fixations to the target at the onset of the critical window due to onset-initial mispronunciations.

[1]Consensus coding to achieve 100% comparable trials is important because low numbers of comparable trials may bias the measures of inter-coder agreement, particularly if trials that are not comparable are more difficult to code.

For our analyses, we regressed the empirical log-odds of fixating the target on the time terms (intercept, linear, quadratic, and cubic time), the within-subject effect of Condition (contrast coded as −0.5 for CPs and 0.5 for MPs), the between-subject effect of Group (contrast coded as −0.5 for ASD and 0.5 for TD), and all two- and three-way interactions between terms. Following Barr et al.'s (2013) recommendation, the full random effects structures were included for each model. All analyses were carried out in RStudio (version 1.1.414) using the lme4 package (version 1.1.17). Models were fit using Maximum Likelihood estimation. Tests of significance were performed using model comparisons. This entailed fitting separate models in which we removed individual parameters (e.g., the interaction between linear time and Group). The reduced models were then compared against the full model and the improvement in model fit was evaluated using −2 times the change in log-likelihood. This is distributed as chi-squared with the degrees of freedom equal to the difference in the number of parameters in the full and reduced model (i.e., 1).

Adjusting for Group Differences—With our full sample of participants, the TD and ASD Groups differed on the assessment measures. Children in the TD Group scored significantly higher on the PLS Auditory Comprehension task (mean raw score = 25.0, SD = 4.7, range = 18-36) compared to children in the ASD Group (mean raw score = 17.7, SD = 5.6, range = 5-31), $b = 7.3$, $F(1,93) = 39.6$, $p < .001$. Similarly, children in the TD Group scored significantly higher on the Mullen VR task (mean raw score = 25.5, SD = 3.9, range = 20-34) compared to children in the TD Group (mean raw score = 21.5, SD = 5.8, range = 8-36), $b = 4.1$, $F(1,93) = 12.5$, $p < .001$. We therefore repeated our main analyses controlling for the group differences in the assessment measures. For these analyses, we used raw scores, rather than standard scores, because our goal is to compare children who are matched in overall verbal or nonverbal ability, not the degree to which their ability is above or below their age level. This is particularly important, because of the intentional difference in age between our TD and ASD groups.

When adjusting for group differences in assessment measures, there is ongoing debate as to whether it is best to compare subsamples that are matched on the measure or to statistically control for differences by including the measure as a covariate (Dennis, Francis, Cirino, Russell, Barnes & Fletcher, 2009; Miller & Chapman, 2001; Plante, Swisher, Kiernan & Restrepo, 1993). We found the same pattern of results using either method. We have included the results using covariate analyses in the Supplementary Materials. We report results using subsample matching, because this additionally allows us to examine the effect of mispronunciations *within* the ASD Group (by comparing different subsamples of children in the ASD Group). This last comparison is important, because it allows us to examine potential variability in word recognition accuracy within the ASD Group. Indeed, one of the strengths of the current experiment is that our use of the looking-while-listening method allowed us to include a heterogenous sample of children in our ASD Group.

To identify matched subsamples, we used a bootstrap matching package available in R (https://github.com/tjmahr/bootmatch). For each of our assessment measures we set the caliper to 2 (i.e., a matched pair of children could not differ by more than 2 points) and ran 100 bootstrap samples to identify the optimal set of matched pairs that maximized the size of our matched subsamples. The procedure yielded two subsamples for each Group: children who were *matched* with children from the other Group and children who were *unmatched*. Unmatched children's scores fall outside of the range of scores for the other Group, therefore there were no children in the other Group with whom to match these children. Unmatched children in the ASD Group had age-equivalent scores that were below 11 months for the PLS-4 and below 14 months for the Mullen. Finding matched children in the TD Group was not possible, because typically-developing children at this age would not be able to perform our experimental task.

Using PLS AC raw scores as the matching variable, there was a matched subsample of 22 children from each Group and an unmatched subsample of 21 children in the ASD Group and 1 child in the TD Group.[2] The matched subsamples of children in the ASD Group and TD Groups did *not* differ in their PLS AC scores [$b = .23$, $F(1,42) = .03$, $p > .85$], confirming that our subsample matching procedure was successful. Within the ASD Group, children in the unmatched subsample had significantly lower PLS AC scores compared to children in the matched subsample [$b = -11.2$, $F(1,41) = 94.1$, $p < .001$], indicating that the different ASD subsamples captured significant heterogeneity within our ASD Group.

Using Mullen Visual Reception raw scores as the matching variable, there was a matched subsample of 31 children in each Group and an unmatched subsample of 15 children in the ASD Group. The matched subsamples of children in the ASD and TD Groups did *not* differ in their Mullen VR scores [$b = -.03$, $F(1,60) = .001$, $p > .97$], confirming that our subsample matching procedure was successful. Within the ASD Group, the children in the unmatched subsample had significantly lower Mullen VR scores compared to children in the matched subsample [$b = -12.1$, $F(1,44) = 108.7$, $p < .001$], indicating that the different ASD subsamples capture significant heterogeneity within our ASD Group.

Results

Group Comparisons

We first examined whether there was an effect of mispronunciations on word recognition accuracy and whether this effect differed between Groups, when using the full sample (see Figure 1). There was a significant effect of Condition on the intercept [$b = -.27$, $\chi^2(1) = 26.4$, $p < .001$], quadratic [$b = .72$, $\chi^2(1) = 13.5$ $p < .001$], and cubic [$b = .34$, $\chi^2(1) = 5.7$ $p < .05$] time terms. Children were overall less accurate, with a shallower asymptote in peak accuracy, and a slower increase in accuracy from baseline in the MP compared to CP Condition. The Condition by Group interaction did *not* significantly improve model fit for any time terms, $\chi^2(1)$'s < 2, p's > .16. This indicates that the effect of mispronunciations on children's word recognition accuracy was the same for both Groups.

Although both Groups were equally affected by mispronunciations, they did not have the same level of overall accuracy in word recognition (when collapsing across CP and MP trials). There was a significant effect of Group on the intercept [$b = .42$, $\chi^2(1) = 18.3$, $p < .001$], linear [$b = 1.2$, $\chi^2(1) = 11.4$, $p < .001$], and quadratic [$b = -.70$, $\chi^2(1) = 10.4$, p

[2]The combined numbers of children in the matched and unmatched subsamples are less than the total number of children in our full sample. This is because there were extra children within each group who were matchable (i.e., their scores were within the range of the other group), but were not matched with another child from the other Group.

= .001] time terms. Children in the TD Group were overall more accurate, with a greater average increase in accuracy over time, and a steeper peak asymptote in accuracy compared to children in the ASD Group. This difference in word recognition accuracy between Groups was expected based on the Group differences in our assessment measures: children in the TD Group had significantly better receptive language skills compared to children in the ASD Group. These differences in the strength of children's word recognition accuracy, however, may affect the extent to which children's lexical knowledge influences their ability to detect changes phonemes between correct and mispronunciations. Specifically, children with stronger lexical knowledge may be less affected by mispronunciations. Therefore, it is important to re-examine the effect of mispronunciations between groups after controlling for differences in word recognition accuracy.

Subsample Comparisons

We next examined whether the effect of mispronunciations on word recognition accuracy differed between Groups, when using subsamples of children in the ASD and TD Group who were matched on PLS AC raw scores (see Figure 2). Consistent with the results from our full sample, the Condition by subsample Group interaction did not significantly improve model fit for any time terms, $\chi^2(1)$'s <.41, p's>.52. When children in the ASD and TD Groups were matched in receptive language skills and word recognition accuracy, they were still equally affected by mispronunciations. Moreover, the effect of subsample Group did not significantly improve model fit for any time terms, $\chi^2(1)$'s <0.7, p's>.41. Thus, when matched for receptive language skills, children in the ASD and TD Groups no longer differed in their overall word recognition accuracy (when collapsing across CP and MP trials).

Additionally, we examined whether word recognition accuracy and the effect of mispronunciations on word recognition accuracy varied between children in the ASD Group based on differences in their receptive language skills (see Figure 3). The between-subject effect of Group now compares subsamples of children in the ASD Group who were matched vs. unmatched to the TD Group in PLS AC raw scores (contrast coded as −0.5 for matched and 0.5 for unmatched). The Condition by subsample Group interaction did *not* significantly improve model fit for any time terms, $\chi^2(1)$'s < 1.1, p's > .30. There was a significant effect of subsample Group on the intercept [b = −.5, $\chi^2(1) = 13.7$, $p < .001$], linear [b = −2.0 $\chi^2(1) = 13.8$, $p < .001$], and quadratic [b = .65, $\chi^2(1) = 4.7$, $p < .05$] time terms. Children in the unmatched subsample of the ASD Group were overall less accurate, with a smaller average increase in accuracy over time, and shallower peak asymptote in word recognition accuracy compared to children in matched subsample of the ASD Group. Despite these overall differences in word recognition accuracy, children in the matched and unmatched subsamples of the ASD Group were *equally* affected by mispronunciations. This is particularly striking since word recognition accuracy was near chance (floor) for children in the unmatchable subsample.

We expected that children with stronger receptive language skills would have better word recognition accuracy based on prior research (e.g., Fernald, Perfors, & Marchman, 2006). It is possible, however, that this correlation is *not* specific to children's receptive language.

Rather, it may simply reflect that children who perform better on one experimental task perform better on other experimental tasks. Put another way, our subsample matching based on receptive language skills may have yielded high-functioning and low-functioning groups of children with ASD. To rule out this possibility, we repeated our subsample analyses using children's nonverbal cognition, which we did not expect to be related to children's word recognition accuracy.

We compared word recognition accuracy for the subsamples of children in the ASD and TD Group who were matched on Mullen VR raw scores (see Figure 4). The Condition by subsample Group interaction did not significantly improve model fit for any time terms, $\chi^2(1)$'s < 1.3, p's > .25. Therefore, children in the matched subsamples of the ASD and TD Groups were equally affected by mispronunciations. There was a significant effect of subsample Group on the intercept [b = .29, $\chi^2(1) = 6.1$, $p < .05$], linear [b = .99, $\chi^2(1) = 5.1$, $p < .05$], and quadratic [b = −.60, $\chi^2(1) = 5.9$, $p < .05$] time terms. This is the same pattern of results as when we compared the full sample of children in the ASD and TD Groups. Thus, when matched for nonverbal cognition, children in the ASD and TD Group still differ in word recognition accuracy.

Additionally, we examined whether word recognition accuracy and the effect of mispronunciations on word recognition accuracy varied between children in the ASD Group based on differences in their nonverbal cognition (see Figure 5). The between-subject effect of Group now compares subsamples of children in the ASD Group who were matched vs. were unmatchable to the TD Group in Mullen VR raw scores (contrast coded as −0.5 for matched and 0.5 for unmatched). The Condition by subsample Group interaction did *not* significantly improve model fit for any time terms, $\chi^2(1)$'s < 1.6, p's > .20. Children in the matched and unmatched subsamples of the ASD Group were *equally* affected by mispronunciations, despite overall differences in word recognition accuracy. There was a significant effect of subsample Group on the intercept [b = −.3, $\chi^2(1) = 5.1$, $p < .05$]. Children in the unmatched subsample of the ASD Group were overall less accurate in word recognition accuracy compared to children in matched subsample of the ASD Group.

Discussion

We used a mispronunciation paradigm to examine the level of phonetic detail in familiar word representations for children with ASD and children with typical development. We found that children with ASD, like the TD group, were sensitive to mispronunciations. That is, they were significantly less accurate in looking at the target object when it was labeled using a mispronunciation compared to a correct pronunciation. Indeed, the effect of mispronunciations on children's accuracy was the same for children with ASD and children with TD, despite the fact that children with TD were more accurate overall in familiar word recognition. Finally, we found that children with ASD were equally affected by mispronunciations, regardless of the significant heterogeneity in their receptive language skills and nonverbal cognition. This last result is particularly striking given the wide range of receptive language skills in our sample of participants. Within the ASD group, age-equivalent scores on the PLS-4 ranged from 2 to 28 months and the reported number of words understood on the MB-CDI ranged from 0 to 549. While these differences were associated with children's overall word recognition accuracy, they were *not* associated with the mispronunciation effect. Put another way, all children experienced equivalent decreases in word recognition accuracy on mispronunciation trials, despite differences in language skills and word recognition accuracy on correct pronunciation trials.

Our results indicating that children with ASD and TD were equally affected by mispronunciations even when matched in verbal or nonverbal skills are important, because they eliminate potential confounds in our full-sample analyses. One potential concern was that the effect of a mispronunciation may vary based on the strength of children's lexical knowledge. Additionally, with a bounded measure like accuracy, the effect of a mispronunciation may be underestimated for children with lower accuracy due to floor effects. When children in the ASD group were matched to the TD group in receptive language skills (and subsequently their overall word recognition accuracy), however, we still observed the same effects of mispronunciations.

Taken together, these findings indicate that children with ASD are equally accurate as their TD peers in detecting phonemic changes within words. Moreover, children with ASD and TD have the same level of phonetic detail in their representations of familiar words. These results are *not* consistent with our hypothesis: that children with ASD are biased to process auditory information at the local, rather than global level and would therefore be more affected by mispronunciations. Due to our large sample size and the significant results observed for other effects (e.g., the effect of Condition), we are confident that our null results (i.e., a non-significant difference in the Group by Condition interactions) are not due to a lack of statistical power. Thus, our results are not consistent with the Weak Central Coherence (WCC) account, which predicts that a bias to process information at the local, rather than global level, would make children with ASD *more* sensitive to mispronunciations than TD peers.

Within the domain of language research, there are mixed results with regards to the WCC account. The majority of this research has involved older children and adolescents (no younger than 5 years of age) and has focused on their ability to use global context to resolve local syntactic or semantic ambiguity. Consistent with WCC, children with ASD use global context to resolve local ambiguity less than their TD peers (Booth & Happé, 2010; Frith & Snowling, 1983; Happé, 1997; Jolliffe & Baron-Cohen, 1999; Lópes & Leekam, 2003; Norbury & Bishop, 2002). More recent research has either found that children with ASD and their TD peers do not differ in their use of global context to resolve local ambiguities or that the observed differences are accounted for by group differences in language skills (Brock, Norbury, Einav, & Nation; 2008; Eberhardt & Nadig, 2016; Hoy, Hatton, & Hare, 2004; Norbury, 2005; Riches, Loucas, Baird, Charman, & Simonoff, 2016).

The findings from the current experiment contribute to this literature by examining whether WCC can account for language differences in younger children with ASD in a task that does not involve ambiguity. Contrary to the WCC account, we found that children with ASD are just as affected by mispronunciations as their TD peers, regardless of whether children with ASD were matched to their TD peers on nonverbal or verbal IQ. These findings are consistent with other research in which toddlers with ASD were just as disrupted by the presence of distractors with perceptual or semantic overlap to the named target as their TD peers who were matched in nonverbal and verbal IQ (Ellis Weismer, Haebig, Edwards, Saffran, & Venker, 2016). Taken together, these findings reveal that although children with ASD are less accurate and efficient in lexical processing than their TD peers, these differences do not seem to be the result of a cognitive style or bias involving decreased global sensitivity.

The Weak Central Coherence account is just one of various attempts to characterize the cognitive mechanisms underlying ASD (see reviews by Brown & Bebko, 2012; Pellicano, 2011). Given the growing lack of support for the WCC account in the domain of language, we believe it is important for future research examining language learning in ASD to consider alternative explanations. For instance, prediction plays an important role in both language learning and comprehension, and several researchers have posited prediction deficit accounts of ASD (Gomot & Wicker, 2012; Sinha et al., 2014; Van De Cruys et al., 2014). Results from a recent investigation by Green and colleagues (2019) found that adolescents with ASD exhibited prediction errors for both social and non-social visual stimuli that were associated with the severity of autism symptoms. Future research is needed to explore the role of prediction deficits in language learning by children with ASD.

Based on findings of the current study, we offer tentative implications for clinical practice. Clinical practitioners should be aware that children with ASD are affected by mispronunciations to the same extent as their peers with TD. Like their TD peers, children with ASD are able to overcome mispronunciations of words to correctly identify the intended target. These results suggest that speech perception deficits (or atypical patterns of speech perception) at the word level are unlikely to be implicated in the vocabulary delays evidenced by many young children with ASD and that there may not be a need to focus specifically on speech perception skills in intervention.

Much of the research literature on ASD is focused on identifying deficits. However, it is important to identify relative strengths, as well as weaknesses, for children with ASD. Our findings suggest that, contrary to the claims of the WCC account, young children with ASD do not display more veridical speech perception during lexical processing than their TD peers matched on receptive language or nonverbal cognition. It is important to identify both similarities and differences in the mechanisms underlying language development for children with ASD compared with TD children in order to better understand learning contexts that can facilitate their language functioning.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Funding: This study was funded by an NIDCD grant (RO1 DC012513) and an NICHD core grant to the Waisman Center (U54 HD090256).

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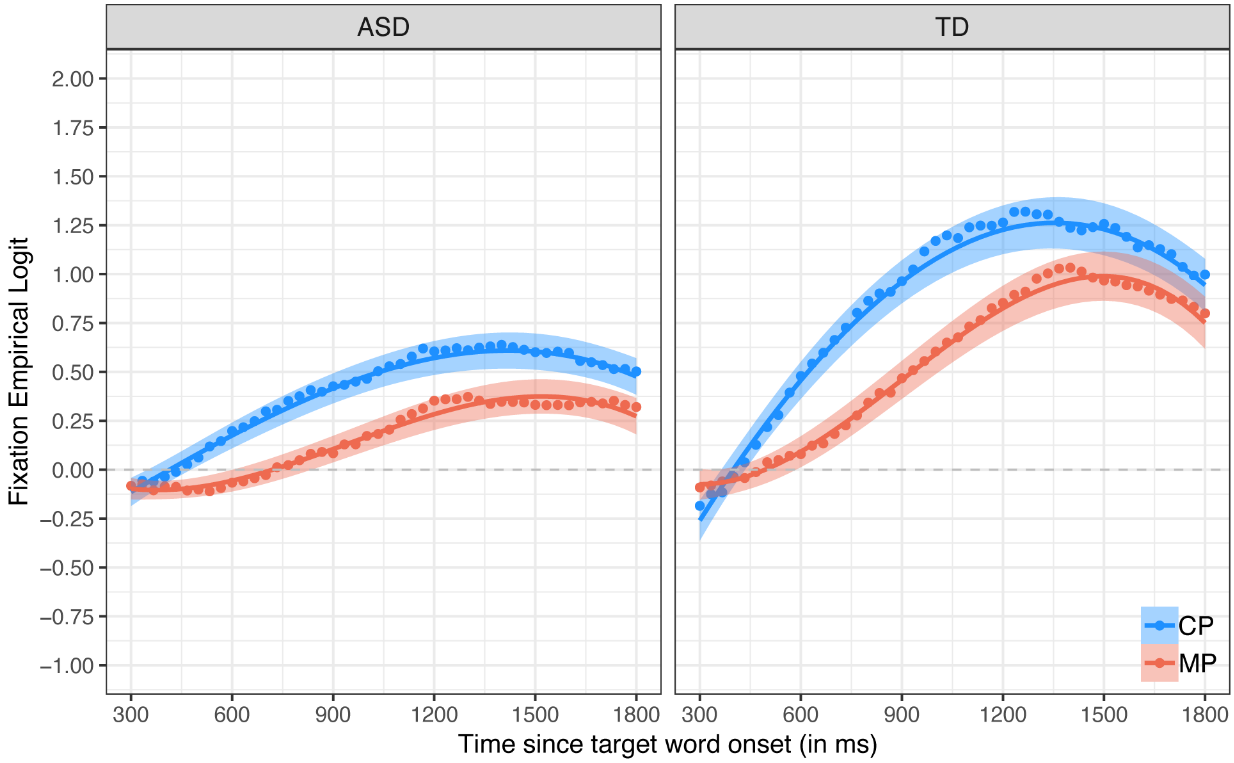

Figure 1.

Time course of children's fixations to the target object on trials with Correct Pronunciations (CP; in blue) and Mispronunciations (MP; in red) of the target word. Time courses are plotted separately for the ASD and TD Group (left and right panel). Fixations are plotted as the empirical log-odds. Data points are the observed data averaged across children. The lines are growth curve fits with ribbons representing +/− 1 SE. The dashed horizontal line at empirical log-odds of 0 represents chance (i.e., equal fixations to both the target and distractor object).

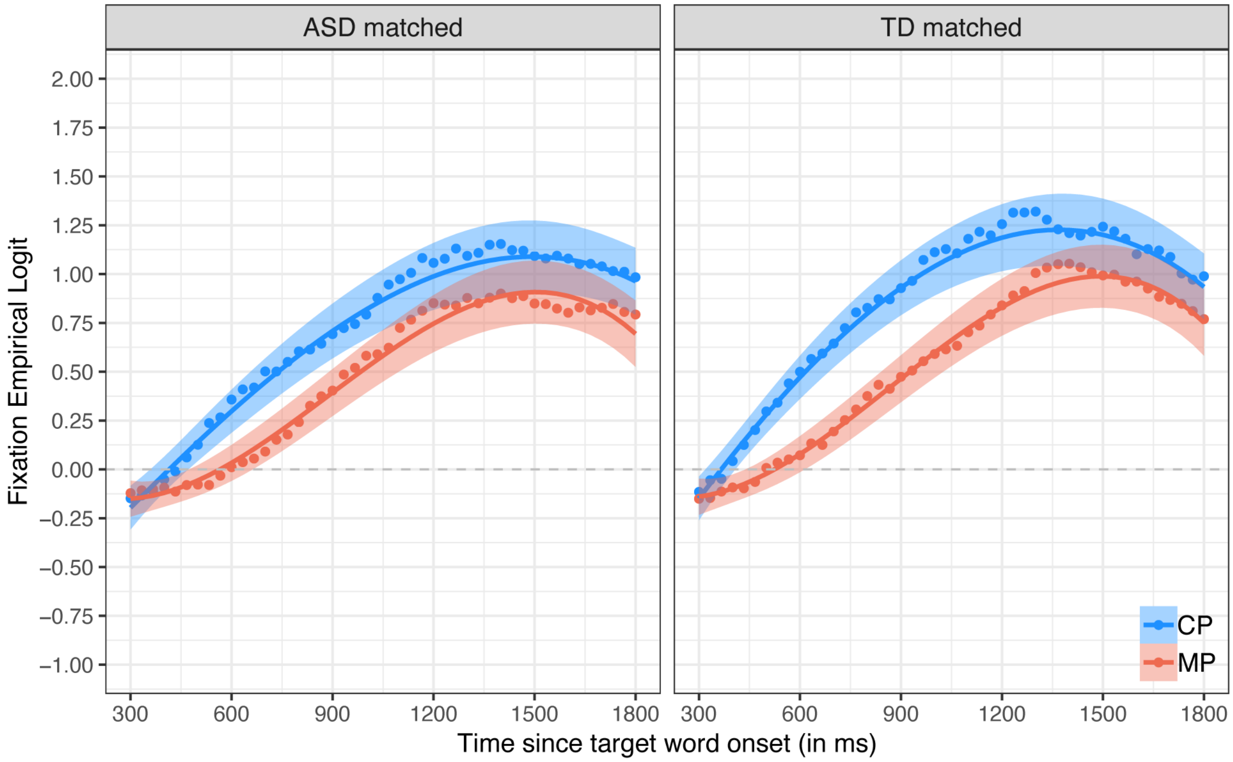

Figure 2.

Time course of children's fixations to the target object on trials with Correct Pronunciations (CP; in blue) and Mispronunciations (MP; in red) of the target word. Time courses are plotted separately for subsamples of the ASD and TD Groups that were matched in PLS Auditory Comprehension scores (left and right panel). Fixations are plotted as the empirical log-odds. Data points are the observed data averaged across participants. The lines are growth curve fits with ribbons representing +/− 1 SE. The dashed horizontal line at empirical log-odds of 0 represents chance (i.e., equal fixations to both the target and distractor object).

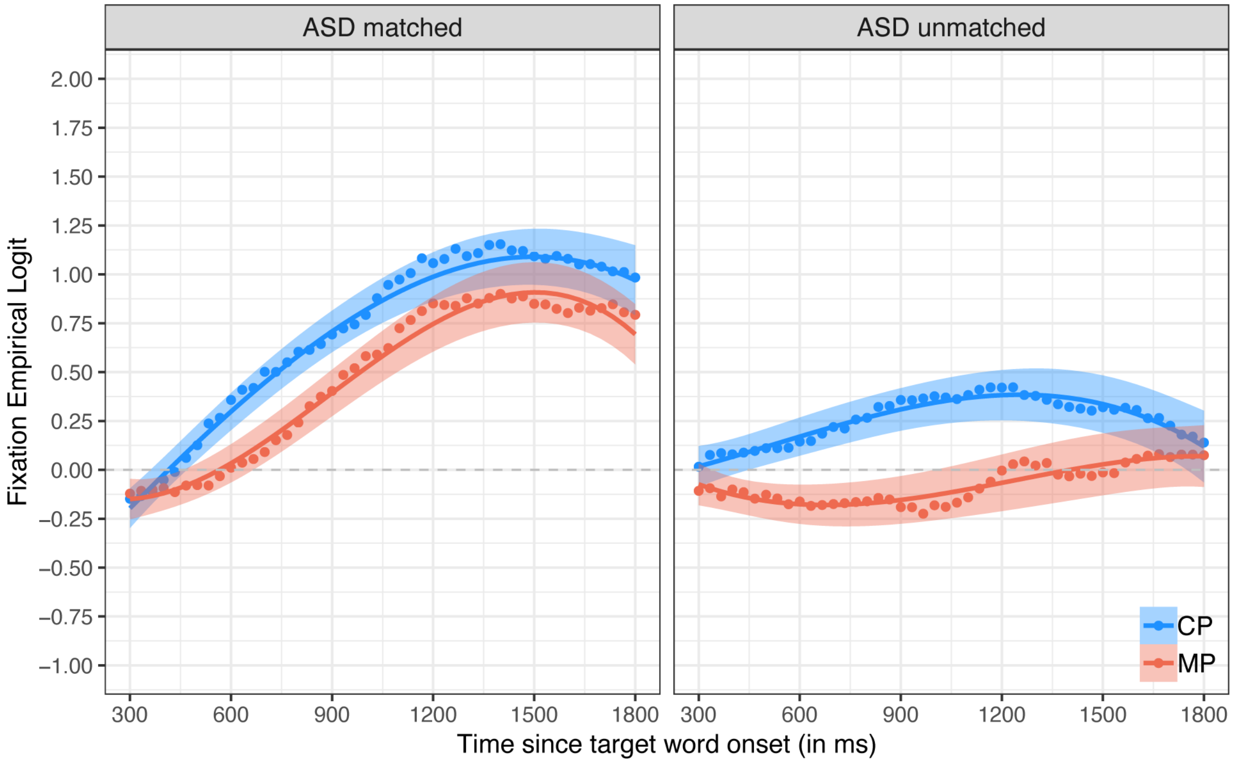

Figure 3.

Time course of children's fixations to the target object on trials with Correct Pronunciations (CP; in blue) and Mispronunciations (MP; in red) of the target word. Time courses are plotted separately for subsamples of the ASD Group that were matched and unmatched (left and right panel) to the TD Group in PLS Auditory Comprehension scores. Fixations are plotted as the empirical log-odds. Data points are the observed data averaged across participants. The lines are growth curve fits with ribbons representing +/− 1 SE. The dashed horizontal line at empirical log-odds of 0 represents chance (i.e., equal fixations to both the target and distractor object).

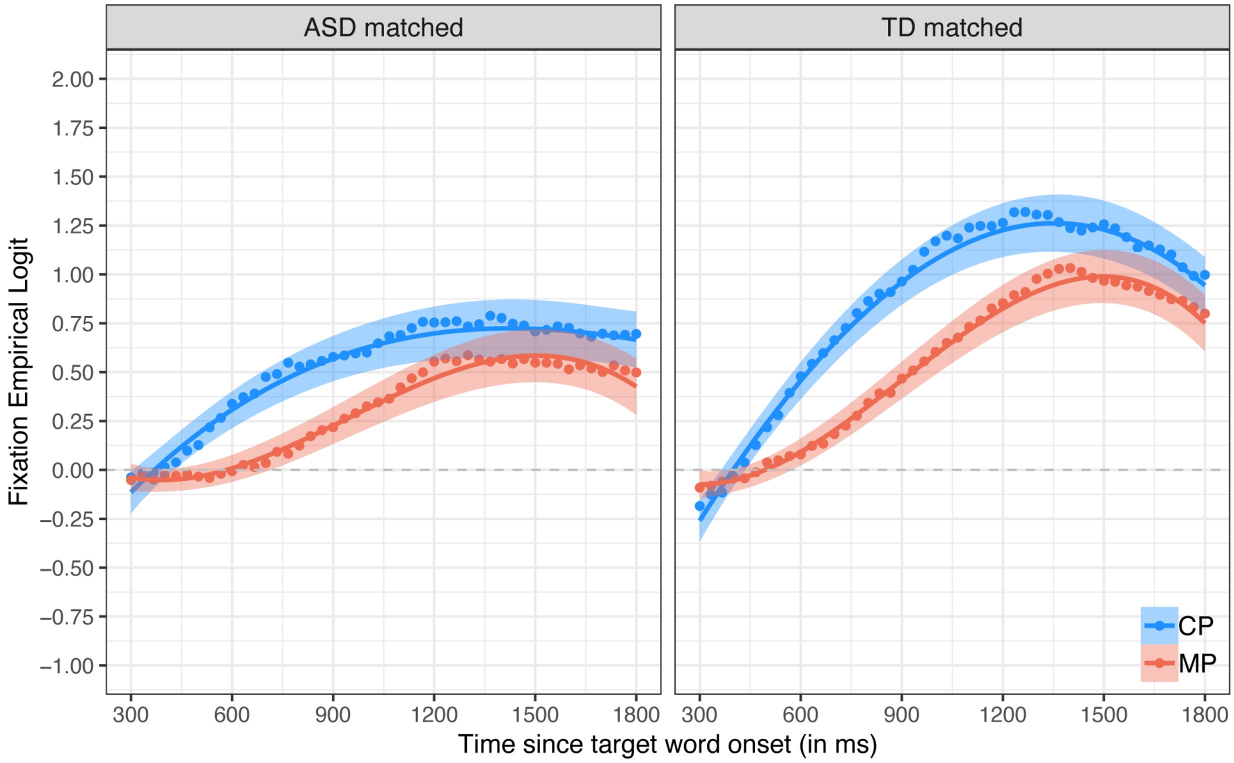

Figure 4.
Time course of children's fixations to the target object on trials with Correct Pronunciations (CP; in blue) and Mispronunciations (MP; in red) of the target word. Time courses are plotted separately for subsamples of the ASD and TD Groups that were matched in Mullen Visual Reception scores (left and right panel). Fixations are plotted as the empirical log-odds. Data points are the observed data averaged across participants. The lines are growth curve fits with ribbons representing +/− 1 SE. The dashed horizontal line at empirical log-odds of 0 represents chance (i.e., equal fixations to both the target and distractor object).

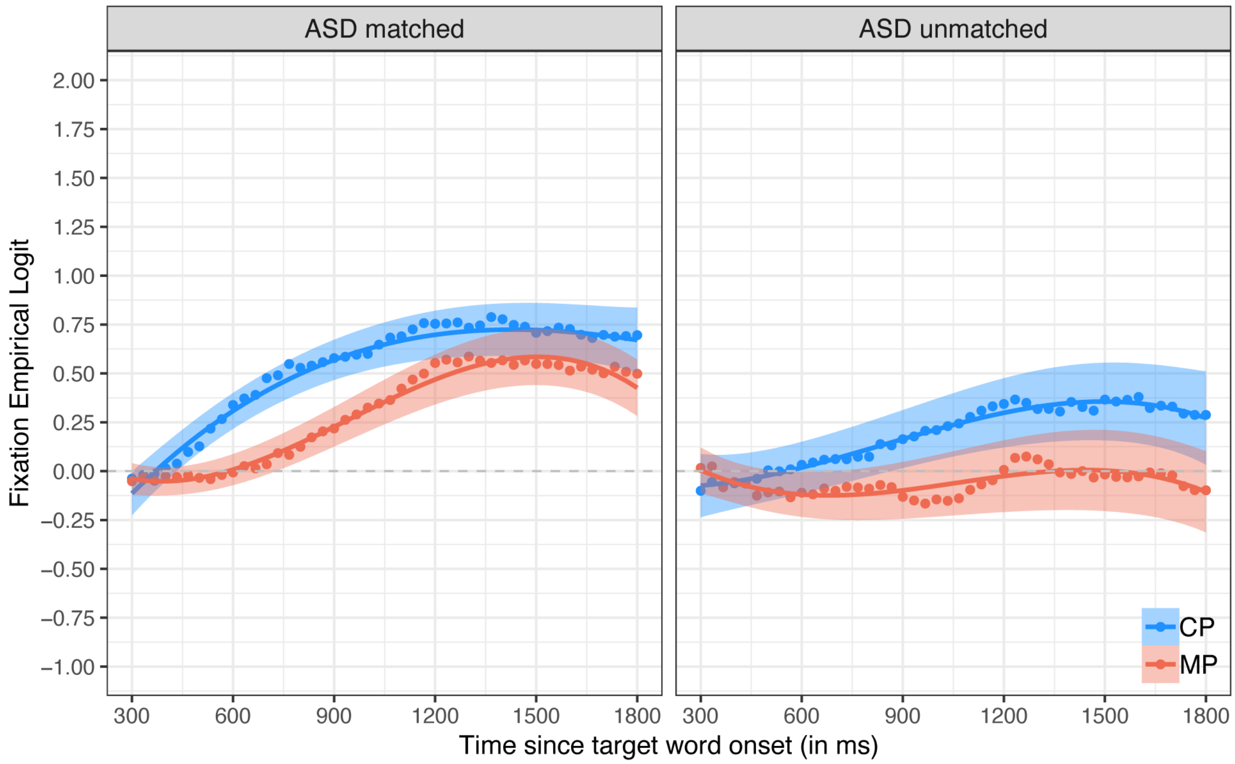

Figure 5.

Time course of children's fixations to the target object on trials with Correct Pronunciations (CP; in blue) and Mispronunciations (MP; in red) of the target word. Time courses are plotted separately for subsamples of the ASD Group that were matched and unmatched (left and right panel) to the TD Group in Mullen Visual Reception Scores. Fixations are plotted as the empirical log-odds. Data points are the observed data averaged across participants. The lines are growth curve fits with ribbons representing +/− 1 SE. The dashed horizontal line at empirical log-odds of 0 represents chance (i.e., equal fixations to both the target and distractor object).

Table 1.

Participant characteristics for the typically-developing (TD) and autism spectrum disorders (ASD) groups. Receptive language was measured using children's raw scores on the PLS Auditory Comprehension scale. Nonverbal cognition was measured using children's raw scores on the Mullen Visual Reception scale. Receptive vocabulary was measured using the Communicative Development Inventory (words and sentences form). Autism severity was measured by the Autism Diagnostic Observation Schedule-2 (ADOS-2) standardized calibrated severity scores. Race/Ethnicity abbreviations are for Native American, multiracial/ other, and Hispanic/Latino.

	TD (*n* = 31)		**ASD (*n* = 64)**	
	Mean (SD)	**Range**	**Mean (SD)**	**Range**
Age (months)*	20.45 (1.69)	18-24	30.61 (3.39)	24-36
Maternal education (years)*	15.90 (2.21)	12-23	14.02 (2.35)	10-25
Receptive Language*	25.00 (4.68)	18-36	17.69 (5.58)	5-31
Nonverbal Cognition*	25.52 (3.85)	20-34	21.45 (5.81)	8-36
Receptive Vocabulary*	456.90 (118.58)	248-640	216.73 (139.83)	0-549
Autism severity	-	-	8.36 (1.63)	4-10
Race/Ethnicity	29 White		58 White	
	0 Black		2 Black	
	0 Asian		0 Asian	
	0 Nat Am		0 Nat Am	
	2 Multi		4 Multi	
	1 Hisp/Latn		6 Hisp/Latn	

*indicates Group difference at $p < .05$.