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From word reading to multisentence comprehension: Improvements in brain activity in children with autism after reading intervention

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ABSTRACT

Background: Children with ASD show a unique reading profile characterized by decoding abilities equivalent to verbal abilities, but with lower comprehension skills. Neuroimaging studies have found recruitment of regions primarily associated with visual processing (e.g., fusiform gyrus and medial parietal cortex), but reduced activation in frontal and temporal regions, when reading in adults with ASD. The purpose of this study was to assess neural changes associated with an intense reading intervention program in children with ASD using three fMRI tasks of reading.

Methods: 25 children with ASD were randomly assigned to a treatment (ASD-EXP) or waitlist group (ASD-WLC). Children participated in a reading intervention program (4-hour sessions per day, 5 days a week for 10 weeks). We utilized three tasks: word, sentence, and multisentence processing, each with differential demands of reading comprehension. fMRI data were acquired at each of two scanning sessions 10-weeks apart.

Results: Across tasks, post-intervention results revealed that the ASD-EXP group showed greater activation in bilateral precentral gyrus and the postcentral gyrus, visual processing regions (e.g., occipital cortex, fusiform gyrus), and frontal regions. In the word task, left thalamus and the right angular gyrus (AG) activation was unique to the ASD-EXP group post-intervention. Sentence tasks showed differential activation of core language areas (e.g., IFG, IPL) post-intervention.

Conclusions: Our results provide evidence for differential recruitment of brain regions based on task demands in children with ASD, and support the potential of targeted interventions to alter brain activation in response to positive gains in treatment. Children with ASD have a different reading profile from other reading disorders that needs to be specifically targeted in interventions.

1. Introduction

Children with autism spectrum disorder (ASD) present with varying degrees of language impairment, from being primarily nonverbal to mild articulation, vocabulary, and idiosyncratic language differences (Mody and Belliveau, 2013). Even children with ASD who have intellectual functioning in the average range may have deficits in both receptive and expressive language (Kjelgaard and Tager-Flusberg, 2001). Research has shown that reading comprehension is highly correlated with an individual's ability to understand spoken language (Gernsbacher, 1990; Perfetti and Tan, 2013). As children with ASD develop into school-aged years, difficulties with language processing, especially receptive language deficits, often lead to delays in acquiring the pre-reading skills needed to be a successful reader (Davidson and Ellis Weismer, 2014). One of the models of reading development, *The Simple View of Reading*, posits that there are two primary precursors necessary to develop the skills needed to acquire age-appropriate reading comprehension skills: decoding and listening comprehension skills (Gough and Tunmer, 1986). Deficits in either of these areas may lead to poor reading comprehension. In a study that applied the *Simple View of Reading* model to children with ASD, the degree of reading comprehension deficits in ASD children was directly correlated with how they performed on tasks of word decoding and oral language comprehension (Nation et al., 2006).

Abbreviations: ASD, autism spectrum disorder; fMRI, functional magnetic resonance imaging; ASD-EXP, children with ASD in the treatment group; ASD-WLC, children with ASD in the waitlist control group; LIOG, left inferior occipital gyrus; LFFG, left fusiform gyrus; LSTG, left superior temporal gyrus; LPCG, left precentral gyrus; LSPL, left superior parietal lobule; LSMA, left supplementary motor area; LIFG, left inferior frontal gyrus; LMFG, left middle frontal gyrus; LTHAL, left thalamus; ADOS, Autism Diagnostic Observation Schedule; ADI, Autism Diagnostic Interview-Revised; SORT-R, Slosson Oral Reading Test - Revised; GORT-4, Gray Oral Reading Test – Fourth Edition; WASI, Wechsler Abbreviated Scale of Intelligence; V/V, Visualizing and Verbalizing

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Studies that have assessed word decoding and oral comprehension in children with ASD have collectively found decoding abilities to be relatively equivalent to verbal abilities, but oral comprehension to be significantly lower than would be expected given verbal and decoding skills (Nation et al., 2006; Norbury and Nation, 2011; Ricketts et al., 2013). Recent neuroimaging research may provide the neural bases to this phenomenon seen in children with ASD. For example, children with high-functioning ASD rely more on visuospatial processing regions of the brain, including the ventral temporal cortex, to interpret language as a compensatory mechanism in order to reduce the burden of language processing (Sahyoun et al., 2010). As such, it may be the case that word decoding, which relies more heavily on printed word recognition skills is more intact in children with ASD. This is further supported by neuroimaging studies that have found recruitment of regions primarily associated with visual processing (e.g., fusiform gyrus and medial parietal cortex) of words and sentences in adults with ASD, suggestive of the pervasiveness of this pattern across the lifespan (Samson et al., 2012). A recent meta-analysis further illustrated these findings in which increased right-hemisphere and atypical posterior activation were found primarily for individuals with ASD who demonstrated poorer performance on language measures (Herringshaw et al., 2016). Overall these findings are consistent with the cortical underconnectivity model of ASD that suggests stimuli can be interpreted either visually or verbally. This is due to brain regions associated with language and visuospatial processing being substantially less functionally integrated in individuals with ASD as compared to healthy-matched controls (Just et al., 2004).

The second component, listening comprehension relies heavily on the interpretation of pragmatics and integration of semantic and contextual information. This is one of the main difficulties noted in the literature, with verbal children with ASD showing limited use and understanding of social contextual information (Mody and Belliveau, 2013). Research investigating different profiles of children with reading difficulties have found that children who have adequate decoding abilities but reading comprehension deficits make up a specific subgroup of children with reading disorders (Catts et al., 2005). It is likely that a large proportion of children with ASD fall within this category. This is supported by pervious neuroimaging research that has found that individuals with ASD show deficits in pragmatics, evident by reduced activation in frontal and temporal regions, when reading sentences that required social integration (Groen et al., 2010), contextual integration (Kana and Wadsworth, 2012), and pragmatics and syntax (Groen et al., 2008).

Knowledge of this distinct reading profile and its neural correlates is important and helpful in identifying appropriate reading intervention for children with ASD (Calderoni et al., 2016). Our previous studies (Murdaugh et al., 2016; Murdaugh et al., 2015) revealed that utilizing an intervention that targets visual processing to improve reading comprehension not only showed behavioral improvements in reading comprehension in children with ASD, but also showed changes in both resting state functional connectivity and task-based brain activation. The current functional MRI study is focused on the specific processes, in progression of complexity, necessary for adequate reading comprehension. Explicitly, we used a series of task-based fMRI experiments in a pre-post design to determine what specific processes are most affected by the intervention. We utilized three tasks: a word, sentence, and multisentence processing task, each with specific skills necessary for reading comprehension, each task building upon the preceding one. The word task utilizes decoding, phonological awareness, and semantic knowledge; the sentence task utilizes integration of vocabulary knowledge and morphosyntax; and the multisentence task requires integration of all of these components in addition to pragmatics and inferential knowledge. Across all tasks, there is also a specific need for visual imagery in order to interpret these tasks. With regards to the *Simple View of Reading* theory, it aligns well with another interventional theory of cognition which has practical applications to the intervention selected for this study. Specifically, the Dual Coding Theory (Sadoski and Paivio, 2001) proposes that when specifically interpreting verbal information, there are two distinct systems working in tandem, a verbal system and a nonverbal, or visual imagery, system.

Our study assessed each of these tasks before and after an intense reading remediation training program, The Visualizing and Verbalizing for Language Comprehension and Thinking (V/V) intervention, in order to break down the core areas of neural change in regards to each task. This will better inform us about the focus of targeted intervention and to increase our knowledge of nature and extent of brain plasticity in children with ASD. We hypothesized that each task would utilize different regions within the established reading network (Koyama et al., 2011; Koyama et al., 2010) to accomplish comprehension. Specifically, given the previous literature, we hypothesized that as the task increased in comprehension difficulty, from single word to multisentence, children with ASD would begin utilizing the visualization strategies taught to them during the intervention, translating to increased reliance on visual processing brain regions (e.g., ventral temporal regions, fusiform gyrus, occipital cortex) to aid in reading comprehension.

2. Methods

2.1. All participants

The total number of participants who participated across all 3 experiments (word, sentence, and multisentence) was 25 children with ASD (*mean age* = 10.7 years; *SD* = 1.4; *range* = 8–14 years). The children with ASD were randomly assigned to participate in the V/V Intervention either between pre-and-post-imaging sessions (Experimental group; ASD-EXP; $n = 13$) or after completing both imaging sessions (Waitlist control group; ASD-WLC; $n = 11$; see Table 1 for sample sizes for each experiment). ASD diagnosis was determined by a licensed clinical psychologist using the Autism Diagnostic Observation Schedule (ADOS: Lord et al., 2000) and the Autism Diagnostic Interview-Revised (ADI: Lord et al., 1994). All participants with ASD were recruited from Birmingham, and surrounding cities in Alabama, as well as the Lindamood-Bell Learning centers recruited potential participants through their centers across the country. All participants with ASD met the following inclusion criteria: ages from 8 to 13 years, current diagnosis of ASD as specified above, right-handed, and be recommended for the V/V intervention, as described below (Murdaugh et al., 2016; Murdaugh et al., 2015). The children with ASD were identified as having difficulties with reading comprehension as indexed by having average word decoding abilities but poor comprehension (Slosson Oral Reading Test - Revised (SORT-R) reading score of at least 37th percentile and/or a Gray Oral Reading Test – Fourth Edition (GORT-4) accuracy score of at least 25th percentile, a GORT-4 comprehension score below 37th percentile). Additionally, all participants needed to have a Verbal IQ score of at least 75, as measured by the Wechsler Abbreviated Scale of Intelligence (WASI).

2.1.1. Ethical considerations

This study was approved by the UAB Institutional Review Board, and all participants' legal guardians gave written informed consent and all participants gave written informed assent.

2.2. Reading intervention program

This study utilized The Visualizing and Verbalizing for Language Comprehension and Thinking (V/V) Intervention. This intervention was developed in order to promote oral and written language comprehension and develop higher order thinking skills (Bell, 1991a, 1991b; Johnson-Glenberg, 2000). V/V was selected specifically for our study given the use of nonverbal sensory input in order to remediate reading deficits. The intervention was designed to be intensive (4-hour sessions per day, 5 days a week for 10 weeks). Participants worked one-on-one