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"Decoding versus comprehension": Brain responses underlying reading comprehension in children with autism

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ABSTRACT

Despite intact decoding ability, deficits in reading comprehension are relatively common in children with autism spectrum disorders (ASD). However, few neuroimaging studies have tested the neural bases of this specific profile of reading deficit in ASD. This fMRI study examined activation and synchronization of the brain's reading network in children with ASD with specific reading comprehension deficits during a word similarities task. Thirteen typically developing children and 18 children with ASD performed the task in the MRI scanner. No statistically significant group differences in functional activation were observed; however, children with ASD showed decreased functional connectivity between the left inferior frontal gyrus (LIFG) and the left inferior occipital gyrus (LIOG). In addition, reading comprehension ability significantly positively predicted functional connectivity between the LIFG and left thalamus (LTHAL) among all subjects. The results of this study provide evidence for altered recruitment of reading-related neural resources in ASD children and suggest specific weaknesses in top-down modulation of semantic processing.

1. Introduction

Language and communication deficits are a core diagnostic feature of autism spectrum disorders (ASD; American Psychiatric Association, 2013). These deficits commonly extend to impairments in reading, especially reading comprehension (Nation, Clarke, Wright, & Williams, 2006). Reading comprehension involves two component functions: decoding (translating written symbols into phonetic sounds) and comprehension (extracting meaningful message from the text) (Perfetti, Landi, & Oakhill, 2005). Although decoding is necessary for reading comprehension, it is often not sufficient. Despite evidence of intact decoding ability (Brown, Oram-Cardy, & Johnson, 2013; O'Connor & Klein, 2004), children with ASD commonly struggle with understanding the meaning of written text. In other words, the core of this issue is a specific deficit in reading comprehension but not in general reading abilities. For example, a previous study found that approximately 35% of children with ASD could read single words but had a reading comprehension ability that was at least one standard deviation below their level of word accuracy (Nation et al., 2006). Similarly, reviews of academic ability indicate reading comprehension as a common weakness of high-functioning children with ASD, despite their intact basic reading skills (Brown et al., 2013; Huemer & Mann, 2010; Whitby & Mancil, 2009). This is a significant deficit to note, as reading comprehension deficits tend to persist throughout development and greatly impact the ability to learn and perform academically (Ricketts, Sperring, & Nation, 2014). Furthermore, it is important to note that this group of children often goes unnoticed in the classroom due to their "normal" word-reading accuracy (Nation & Angell, 2006). The neurobiological mechanisms behind this specific profile of reading comprehension deficit are largely unknown and require further examination. Gaining a better understanding of the underlying neural mechanisms behind reading comprehension in ASD will allow for the design of appropriate and targeted early interventions in the long-run.

Reading comprehension may fail in ASD because of a weakness in maintaining and utilizing semantic knowledge (Frith & Snowling, 1983; Harris et al., 2006; Henderson, Clarke, & Snowling, 2011; Tager-Flusberg, 1985). For example, a study of homonym priming found that children with ASD show context-appropriate priming at short interstimulus intervals but inappropriate priming at longer interstimulus intervals (Henderson et al., 2011). This indicates that children with ASD have intact access to semantic information but impaired top-down maintenance or control of semantic processing. Another study found that individuals

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with ASD did not show an advantage for recalling semantically-encoded words versus phonologically-encoded words; this suggests an altered relationship between semantic memory and long-term memory in ASD (Toichi & Kamio, 2002). Such impairments in semantic processing may give rise to the reading comprehension deficits commonly observed in ASD.

However, reading comprehension may also fail for reasons related to the general cognitive processing styles in ASD. Specifically, reading comprehension requires certain specific cognitive abilities that are often reported to be impaired in children with ASD. The ability to convert smaller components into a holistic and meaningful message, integrate previous knowledge acquired from the text, reference background knowledge, make inferences, monitor comprehension, and maintain verbal stimuli in working memory is essential to comprehension (Keene & Zimmermann, 1997; Nation & Angell, 2006; Perfetti et al., 2005). Increased focus of ASD children on smaller details of information at the expense of the perceptual whole, as described by the weak central coherence (WCC) account (Frith, 1989; Happé & Frith, 2006), may negatively impact text integration. Understanding text often requires inferring the thoughts and actions of characters, which is challenging for individuals with ASD due to poor Theory of Mind (ToM; Baron-Cohen, Leslie, & Frith, 1985; Mason, Williams, Kana, Minshew, & Just, 2008). Thus, it may be difficult to untangle deficits that are specific to reading ability (e.g. semantic processing) from deficits that reflect more global cognitive alterations in ASD. Therefore, in the current study, we examined the neurofunctional bases of reading comprehension in ASD by focusing on semantic processing. We chose a word similarities task that required semantic retrieval, maintenance, and comparison, but was independent of text integration and ToM.

At the neural level, language comprehension has been associated with a specific set of brain regions primarily in the left hemisphere, which include the left posterior superior temporal gyrus (LSTG) – associated with lexical access (Roux et al., 2012) – and the left inferior frontal gyrus (LIFG) – implicated in semantic processing (Bookheimer, 2002; Poldrack et al., 1999; Turkeltaub, 2003). The LIFG in particular has been associated with top-down modulation of semantic processing, such as semantic response selection among competing alternatives (Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997; Thompson-Schill, D'Esposito, & Kan, 1999). In addition to these two primary regions, the brain's *reading network* consists of several other nodes. This network is typically left-lateralized and involves the frontal, temporoparietal, and occipitotemporal regions (Houdé, Rossi, Lubin, & Joliot, 2010); it includes the inferior occipital gyrus (IOG), fusiform gyrus (FG), STG, pre/postcentral gyrus, intraparietal sulcus (IPS), supplementary motor area (SMA), IFG, middle frontal gyrus (MFG), and thalamus (Koyama et al., 2011). The visual word form area (VWFA), located on the left border of the FG, also has been implicated especially at the earlier stages of reading (Dehaene & Cohen, 2011; Dehaene, Le Clec'H, Poline, Le Bihan, & Cohen, 2002).

While much research has focused on language more generally in ASD, little is known about the neural correlates of reading comprehension deficits in the ASD population. Previous fMRI studies of lexical semantic processing (Harris et al., 2006) and sentence comprehension (Just, Cherkassky, Keller, & Minshew, 2004) have reported increased LSTG and decreased LIFG activation in adults with ASD. These findings have been interpreted in terms of shallow semantic processing and poor integration of linguistic information in ASD with an overemphasis on individual details. Another study used a task similar to a word similarities task, in which subjects had to decide categorical membership of a visually presented word (Gaffrey et al., 2007). This study found that adults with ASD recruited additional bilateral extrastriate visual areas, consistent with more perceptually-based lexical representations (Gaffrey et al., 2007). Importantly, previous studies utilizing fMRI to examine single word reading in ASD have almost exclusively focused on adults, in which the reading network is fully developed (Gaffrey et al., 2007; Harris et al., 2006). In addition, it is significant to note that these studies described above did not intentionally recruit children with ASD with specific reading comprehension deficits.

In fact, only a few studies have utilized neuroimaging to specifically examine children with ASD that have intact decoding ability but impaired comprehension (Murdaugh, Deshpande, & Kana, 2016; Murdaugh, Maximo, & Kana, 2015). One of these studies found that ASD children with specific reading comprehension deficits exhibited decreased activation in the left middle occipital gyrus, left FG, and right cuneus compared to TD children during a reading comprehension task involving high-imagery sentences (Murdaugh et al., 2016). No neuroimaging studies to date have examined this subgroup of children with ASD using a word similarities task. Identifying the nature and function of the reading network in these children is critical as such knowledge would provide more insights into addressing their difficulties in a mechanistic way.

A major aim of our study was to examine neural differences of the reading network during a reading task that was independent of text integration and ToM; this would allow us to adequately differentiate between mechanisms related to semantic processing and general cognitive processing style in ASD. Thus, we used a simple word similarities task that only required decoding, semantic processing, semantic maintenance, and semantic comparison. Although we expected TD and ASD groups to perform similarly on the word similarities task (given evidence of intact decoding), we hypothesized that neural differences could still be evident. (For example, one study assessing single word reading in adolescent boys found that while TD participants and participants with ASD showed similar levels of performance on a word task, they recruited different brain regions including right frontal and temporal gyri (Knaus, Silver, Lindgren, Hadjikhani, & Tager-Flusberg-, 2008)). Specifically, we hypothesized that in our study, ASD children with reading comprehension deficits would exhibit altered recruitment and connectivity of the reading network during the word similarities task, especially among the left frontal regions that are primarily involved in semantic processing and maintenance. We also hypothesized that neuropsychological measures of reading comprehension would be predictive of activation and connectivity of left frontal regions within the reading network. The findings of this fMRI study will be significant in uncovering the neurobiological mechanisms that underlie reading comprehension at the word level in a unique subgroup of children with ASD with specific reading comprehension deficits.

2. Methods

2.1. Participants

Thirteen TD children (*mean age* = 10.5 years ± 1.8), and 18 children with ASD (*mean age* = 10.7 years ± 1.6) participated in this fMRI study (see Table 1 for demographic information). The two groups did not differ on age [$t(29) = 0.43$, $p = 0.67$], FSIQ [$t(28) = 0.70$, $p = 0.49$], verbal IQ [$t(28) = 1.68$, $p = 0.10$], or decoding abilities as assessed by the Slosson Oral Reading Test – Revised [SORT-R; $t(29) = 0.20$, $p = 0.85$]. However, they differed on reading comprehension abilities assessed by the Gray Oral Reading Test, Fourth Edition (GORT-4) Comprehension score [ASD = 76.7 ± 11.5, TD = 105.0 ± 9.8, $t(29) = 7.19$, $p < 0.001$], such that the TD group had average reading comprehension abilities, while the ASD group had lower reading comprehension abilities by greater than 1 standard deviation. All participants were 8–13 years of age,