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Maternal reading fluency is positively associated with greater functional connectivity between the child's future reading network and regions related to executive functions and language processing in preschool-age children

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ABSTRACT

The role of the parent or educator in a child's learning is a key feature in child development. Evidence supports the impact of early language exposure for future language and cognitive abilities and of home reading environment on neural circuits supporting language and reading. As shared parent–child reading is largely contingent on the reading ability of the parent, the aim of the current study was to explore association of parental reading ability on functional connectivity of brain networks involved with reading acquisition in their children.

Twenty-two 4-year-old girls and their mothers participated in the current study. Maternal reading fluency was applied as predictors of functional connectivity analyses of a stories-listening functional MRI task.

Results indicate a positive association between maternal fluency scores and greater functional connectivity between regions in the future reading network and brain regions supporting language and cognitive control in the children.

Maternal reading fluency is important in facilitating development of a child's reading network. Implications regarding shared reading are discussed, and an extended ecological model for child language and literacy development is proposed.

1. Introduction

How does a child acquire reading? Well, not easily. Several models were proposed for this proses but one of the only ones which engages both nature and nurture is the "inside out and outside in" model (Whitehurst & Lonigan, 1998). The inside out part of the model, includes the child's characteristics (or 'nature'). This includes the child's linguistic ability, the ability to translate the letters to sounds which relies on phonological awareness, the understanding and familiarity with graphemes (letters) and cognitive control ability. The outside in factors are the nurturing ones and include home literacy environment (number of books and written materials in the house), the exposure to narratives, the interpretation of it (i.e. semantics) and the child's vocabulary exposure (Whitehurst & Lonigan, 1998). This model emphasizes the importance of a child's exposure to narratives and stories for future reading development. These outside factors and the interaction of the parent with the child, are components of Vygotsky's model for child development which stresses that early environment has a critical role in child development (Vygotsky, 1978). Vygotsky also emphasized the need for constructive role modeling by parents and adult caregivers in developmentally stimulating activities. Vygotsky's theory of the role of the parent in shaping a child's cognitive abilities, specifically in the literacy domain, has been supported by other studies (Aram & Levin, 2001; Aram, Lili Elad-Orbach, & Abiri, 2016). It has been suggested that the level of engagement in the parent-child interaction, especially with the mother, contributes to the developmental trajectory of the child (Aram & Levin, 2001). The basis for this claim is that mothers who more constructively engage with their children from an early stage of development learn more about their child's competencies and therefore, adapt their interaction style to what best fits those competencies (Aram & Levin, 2001). These studies were focused on the parent-child interaction in terms of literacy, based on Bronfenbrenner's ecological model (Bronfenbrenner, 1979) that accounts for socioeconomic status, maternal literacy, the child's literacy tools, and activities at home. The researchers suggested that the more skilled the child with a variety of literacy competencies (e.g., letter knowledge, phonological awareness), the more their mother invokes these skills, thereby "scaffolding" increasingly more advanced literacy activities. This model was reinforced by recent neurobiological evidence showing positive association between early home reading environment and activation of the parietal-

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temporal-occipital multi-modal association cortex in preschool-age children during story listening (Hutton et al., 2015).

The ability to comprehend auditory stimuli shares many neural pathways with reading comprehension (Horowitz-Kraus, Vannest, & Holland, 2013). Neuroimaging data has provided evidence of the reliance of language processing on phonological processing supported by the superior temporal gyrus [Brodmann area (BA) 22] and angular gyrus (BA 39,40), as well as semantics and syntax engaging the inferior frontal gyrus (IFG; BA 44,45) Holland et al., 2007. Narrative and reading comprehension also rely on executive functions (EF), a term used to describe cognitive abilities that underlie learning supported by frontal (BA 6,8,9,10,46) and visual-processing (BA 3,7) brain regions and episodic memory consolidation in the hippocampus (BA 28), as well as multi-modal integration supported by angular and supramarginal gyri (BA 39,40) Horowitz-Kraus et al., 2013.

Recent studies have demonstrated consistent, left-lateralized activation patterns for narrative comprehension, in children (Schmithorst, Holland, & Plante, 2006; Schmithorst, Holland, & Plante, 2007). Specifically, activation has been consistently found in the left IFG (BA 44,45,46; Broca's Area) and the left superior temporal gyrus (STG) and middle temporal gyrus (BA 21,22; Wernicke's Area). According to the memory, unification, and control (MUC) model, the left STG also participates in processes involved in storage and retrieval of linguistic stimuli which get consolidated during the language acquisition period. These processes include phonological, syntactic and grammatical mechanisms (Hagoort, 2006). The trend towards increased frontal and left-lateralization occurs during child development, influenced by genetic programs and environmental stimulation (Lenroot & Giedd, 2006). A critical factor influencing this process is language exposure in the home (Deckner, Adamson, & Bakeman, 2006). There is evidence that children's books can be a potent catalyst for parent-child verbal interaction, in turn supporting language and reading abilities (Deckner et al., 2006; Whitehurst et al., 1988), as well as development of corresponding brain networks (Horowitz-Kraus & Hutton, 2015; Hutton et al., 2015, submitted for publication). Several critical factors seem to moderate the benefits of shared reading on language development and emergent literacy in a child, including socioeconomic status, home reading environment, maternal literacy, and other factors (Bronfenbrenner, 1979). It is therefore not surprising that parental role in literacy development was also emphasized in the 2014 recommendations by the American Academy of Pediatrics promoting reading to children beginning at birth.

Home reading environment (notably access to books and shared reading frequency), an "outside" factor in the "inside out and outside in" model, is positively associated with increased activation in the parietal-temporal-occipital junction, a region related to semantic and language processing and future reading development, in preschool-age children (Hutton et al., 2015). Several programs advocating shared reading, such as *Reach Out and Read*, cite this and other behavioral evidence for the beneficial effect of shared reading on emergent literacy and language ability in children (Klass, Dreyer, & Mendelsohn, 2009). The *Reach Out and Read* program involves pediatricians providing a book and encouragement to parents to engage in daily shared reading with their child in an interactive (dialogic) fashion (Klass et al., 2009; Sharif, Rieber, & Ozuah, 2002; Zuckerman & Khandekar, 2010). This process facilitates literacy development (i.e., looking at the letters and words, understanding the direction of the lines and the overall directionality of reading a book) and abilities as the foundation for future reading development (for review see Zuckerman, 2009). Since the effectiveness of such advice and this program are contingent on caregiver (usually parent) involvement, important questions arise as to parental reading ability. This question is particularly important in households with low socioeconomic status, where reading abilities tend to be disproportionately low (McClelland et al., 2007; Payne, Whitehurst, & Angell, 1994; Sonnenschein & Munsterman, 2002; Whitehurst et al., 1994). Thus, screening parental reading ability has potential value to improve such programs and guide reading interventions. Neuroimaging can provide insights into the influence of parental reading abilities on underlying neurobiology in the child, which is the focus of the current study.

Intact reading is defined as the ability to read fluently (i.e., in a fast and accurate manner) and is critical for skilled reading (Breznitz, 2006). In the context of the factors influencing the child's future reading ability, the exposure to the linguistic stimuli is critical and therefore the relationship between a parent's reading ability and the child's future reading ability is relevant. The current study aims to define whether the parent's reading fluency has an impact on connectivity within the brain network that we know will be needed to support fluent reading in their children as they learn to read. Although there is evidence for a relationship between a parent's reading ability and their child's future reading ability (Black et al., 2012; Hoeft et al., 2007), there is a gap in knowledge regarding the relationship between a parent's reading fluency and neural circuits related to emerging literacy in the child, even before reading is acquired.

The current study was designed to examine the relationship between maternal reading ability and neural circuits related to future reading ability in their 4-year-old children, while listening to stories. Specifically, we were interested in the relationship between maternal reading fluency at the contextual level and brain networks supporting future reading in their children. Neuroimaging data during a stories-listening task was collected from 4-year-old girls and correlated with maternal scores on tests of fluency ability. We hypothesized that due to the critical role of fluency for comprehension, higher maternal reading fluency would be positively correlated with greater functional connectivity in the child's brain regions related to language, EF, and visual processing.

2. Methods

2.1. Participants

Children (n = 22, mean age: 3.83 ± 0.49 years, all right-handed girls) and their mothers (n = 22, mean age: 21.35 ± 3.75 years at the time of testing, education years: x = 13.1 ± 1.46) participated in the current study. All children were within the normal range of nonverbal IQ, none had a history of neurological or emotional disorders or attention difficulties, and all were native monolingual English speakers with no contraindications to MRI. We chose to exclusively include girls in this study to avoid confounding influence of sexual dimorphism in child brain-language development and due to past experience showing greater MRI success rates in girls vs boys at our study age (Rajagopal et al., 2014; Yuan et al., 2009). Written informed consent was obtained from mothers, with verbal assent from the children. The study received Institutional Review Board approval (CHIP study, protocol number: 2010-2537).

2.2. Behavioral measures

All children were administered the Performance and Verbal subtests from the WIPSSI (Wechsler, 1999) to verify normal non-verbal and verbal IQ, respectively. The verbal ability subtest measured receptive language ability by requiring the child to point at the correct picture to a given verbal cue. The nonverbal IQ subtest presents a shape that is missing one part. The child is asked to point at the missing part from several options presented.

To exclude linguistic deficits, phonological awareness was assessed using the Elision subtest from the CTOPP (Wagner, Torgesen, & Rashotte, 1999). In this test the child was requested to omit a sound from an orally given word. The average of the tests from the WIPSSI is 100 with a standard deviation of 15 and for the CTOPP test a scaled score of 10 with standard deviation of 3.

Mothers' reading ability and fluency was assessed using the TOWRE