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The relationship between maternal education and the neural substrates of phoneme perception in children: Interactions between socioeconomic status and proficiency level

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ABSTRACT

Relationships between maternal education (ME) and both behavioral performances and brain activation during the discrimination of phonemic and nonphonemic sounds were examined using fMRI in children with different levels of phoneme categorization proficiency (CP). Significant relationships were found between ME and intellectual functioning and vocabulary, with a trend for phonological awareness. A significant interaction between CP and ME was seen for nonverbal reasoning abilities. In addition, fMRI analyses revealed a significant interaction between CP and ME for phonemic discrimination in left prefrontal cortex. Thus, ME was associated with differential patterns of both neuropsychological performance and brain activation contingent on the level of CP. These results highlight the importance of examining SES effects at different proficiency levels. The pattern of results may suggest the presence of neurobiological differences in the children with low CP that affect the nature of relationships with ME.

1. Introduction

Family socioeconomic status (SES) is associated with many aspects of child health and development, with continued effects seen into adolescence and adulthood. Numerous studies have shown a relationship between SES and neuropsychological functioning, particularly in the domains of language and executive functions (Ardila, Rosselli, Matute, & Guajardo, 2005; Hackman & Farah, 2009; Hackman, Farah, & Meaney, 2010; Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005). In addition, relationships between SES and both brain structure and function have been reported (Hanson et al., 2013; Jednoróg et al., 2012; Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009; Krishnadas et al., 2013; Noble, Houston, Kan, & Sowell, 2012; Otero, 1997; Otero, Pliego-Rivero, Fernandez, & Ricardo, 2003; Raizada, Richards, Meltzoff, & Kuhl, 2008; Sheridan, Sarsour, Jutte, D'Esposito, & Boyce, 2012; Tomarken, Dichter, Garber, & Simien, 2004). Importantly, brain and behavioral differences do not always co-occur, as SES-related differences in neural responses associated with specific cognitive functions such as auditory selective attention have also been found in the absence of any differences in behavioral performance (D'Angiulli, Herdman, Stapells, & Hertzman, 2008; Stevens, Lauinger, & Neville, 2009).

Family SES is typically operationalized using parental education, occupation, or income, either individually or in some combination. Studies examining composite measures of SES and the different components have suggested that maternal education (ME) may be an optimal choice for predicting at least some outcomes including language development, reading, or educational attainment (Bradley & Corwyn, 2003; Fluss et al., 2009; Haveman & Wolfe, 1995; Raviv, Kessenich, & Morrison, 2004). This may be due to its strong associations with multiple parenting behaviors (Augustine, Cavanagh, & Crosnoe, 2009; Bornstein, Hahn, Suwalsky, & Haynes, 2003; Callahan & Eyberg, 2010) many of which have been found to mediate the relationships between SES and child development, such as cognitive stimulation in the environment (Raviv et al., 2004), expectations (Davis-Kean, 2005), selection of academically advantageous early child-care arrangements (Augustine et al., 2009), knowledge about child development, and quantity and quality of child-directed speech (Rowe, 2008).

The latter may be particularly important for language given that the language environment is known to play an important role in shaping language development even before birth. Newborns tested within 75 h of birth can already distinguish between native and non-native vowel sounds (Moon, Lagercrantz, & Kuhl, 2013),

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although they are initially able to discriminate contrasts that are phonemic in languages to which they have had no exposure. This sensitivity to non-native phoneme contrasts begins to decline in the latter part of the first year of life (Cheour et al., 1998; Eimas, 1975; Werker & Tees, 1984), while categorical perception of native phonemes becomes stronger. Categorical perception (CP) refers to greater sensitivity to acoustic variations that cue phonemic categories than to acoustic variations of a similar extent within a phonemic category. The ability to disregard phonemically irrelevant acoustic variability is necessary in order to recognize a wide variety of physically different sounds as exemplars of the same phoneme, which is important given that repeated utterances of the same phoneme vary acoustically both within and across speakers. CP of native phonemes is an important component of language development, as evidenced by the strong relationship between infant phoneme perception and later language abilities (Kuhl et al., 2008), as well as findings implicating CP deficits in at least some cases of specific language impairment (Joanisse & Seidenberg, 1998; Ziegler, Pech-Georgel, George, & Lorenzi, 2011) and dyslexia (Noordenbos & Serniclaes, 2015). This ability continues to develop between the ages of 6 and 12 years, with performance still not reaching adult levels at the upper end of this age range (Bogliotti, 2003; Elliott, Longinotti, Meyer, Raz, & Zucker, 1981; Hazan & Barrett, 2000).

To our knowledge, the relationship between CP of phonemes and ME has only been directly examined in infants in the first year of life, and this work failed to find an association (Liu, Kuhl, & Tsao, 2003; Tsao, Liu, & Kuhl, 2004), although an effect of the quality of maternal vowel clarity on phoneme perception was found (Liu et al., 2003). The failure to find a relationship at this age is consistent with other studies looking at the relationship between parental education and different aspects of cognitive functioning, which have similarly suggested that behavioral differences may not be evident or are variable in the first year to two of life (Mayes & Bornstein, 1995; Roberts & Bornstein, 1999; Tsao et al., 2004). An increasingly strong relationship between ME and language functioning has been found from two to four years of age (Reilly et al., 2010), and Noble et al. (2012) found greater parental-education-related differences in brain volume associated with increasing age in the left inferior frontal and superior temporal gyri in a sample of children and adolescents ranging from 5 to 17 years of age. Thus, it is possible that ME may have an effect on CP and potentially its neural substrates at later ages.

Two neurophysiology studies have linked ME to aspects of auditory processing that could affect the development of phoneme perception. Using an event-related potential measure of selective auditory attention in children aged 3–8 years, Stevens et al. (2009) reported that children of mothers with no college experience showed reduced ability to suppress responses to irrelevant information relative to those with higher ME levels. In a study by Skoe, Krizman, and Kraus (2013) examining auditory brainstem responses, adolescents with mothers who had lower educational levels demonstrated less consistent neural responses to speech over repeated stimulation, weaker encoding of speech-specific information, and greater activity in the absence of auditory stimulation compared to participants with higher ME levels. Both of these studies suggest that lower levels of ME may be associated with noisier, less efficient processing of auditory stimuli including speech sounds.

We previously used fMRI to examine the neural substrates associated with CP in 7–12-year-old children as well as the relationships among level of CP proficiency, associated activation patterns, and the development of reading and phonological processing abilities (Conant, Liebenthal, Desai, & Binder, 2014). While multiple regions in left frontal, temporal, and parietal cortex were activated more for phonemic sounds relative to nonphonemic sounds matched for spectrotemporal complexity, the extent of left lateralization in posterior temporal and parietal regions differed depending on the level of phoneme categorization ability. Specifically, regions of interest analyses revealed that children exhibiting strongly categorical phoneme perception showed left lateralization in these two regions for the phonemic sounds, whereas those with lower categorical proficiency showed right lateralization. In contrast, the proficient categorizing group showed right lateralized activation in these areas for the nonphonemic sounds, while the low CP group showed more bilateral or weak left lateralization. CP proficiency was also found to be strongly related to activation in the left ventral occipitotemporal cortex, an area frequently associated with orthographic processing.

In the current study, we examined the relationships between ME and brain activation during phonemic and nonphonemic discrimination tasks and between ME and performance on measures of intellectual functioning, reading, and phonological processing in the same sample of children, while taking into account CP proficiency level. We hypothesized that higher levels of ME would be positively correlated with performance on the neuropsychological variables, particularly those assessing verbal abilities, and with increased activation associated with the tasks. We expected stronger relationships in children with lower CP given that other studies have found greater effects of SES in at-risk groups (e.g., Monzalvo, Fluss, Billard, Dehaene, & Dehaene-Lambertz, 2012; Tomarken et al., 2004). The location of increased activation could be either in areas subserving CP or in areas not typically recruited for this task, with the latter suggesting compensatory activation.

2. Methods

2.1. Participants

Participants in the fMRI study were 39 monolingual, right-handed children, 7–12 years of age, who had no history of significant neurological illness or injury, hearing impairment, developmental speech, language or learning disorder, chronic medical illness, or psychiatric disorder. Participants as well as at least one of their parents were native speakers of American English. The latter was necessary to ensure that the children were exposed to American English phonemes from birth. Children were excluded if they had fewer than 40 trials remaining in the phonemic (P) or the nonphonemic (N) scanner conditions after removal of trials in which no response was given or excessive movement occurred. Application of this criterion resulted in the exclusion of 6 children. One additional child was excluded due to poor image quality, leaving a final sample of 32 children (Age: Mean (SD) = 10.30 (1.54)). The study protocol was approved by the relevant Institutional Review Board. Parents of all participants gave written informed consent, and children provided written assent.

Based on parent report, none of the children spoke another language fluently, but most (75%) were reported to have some limited knowledge of one or more languages other than English. In this regard, 53.1% were reported to have some knowledge of one other language, while 15.6% and 6.3% had some exposure to two or three additional languages, respectively. In addition, 56.5% played a musical instrument, with varying ranges of experience (0.5–4 years, mean = 2.4 years) and rated proficiency (1 (novice)–5 (virtuoso), mean = 2.6).

Maternal education was assigned a numerical value based on the number of years of education generally associated with the highest level of education achieved. These values were as follows: high school degree = 12; some college, no degree = 13, Associate's degree = 14; Bachelor's degree = 16; some graduate school, no