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Relationship of temporal lobe volumes to neuropsychological test performance in healthy children

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ABSTRACT

Ecological validity of neuropsychological assessment includes the ability of tests to predict real-world functioning and/or covary with brain structures. Studies have examined the relationship between adaptive skills and test performance, with less focus on the association between regional brain volumes and neurobehavioral function in healthy children. The present study examined the relationship between temporal lobe gray matter volumes and performance on two neuropsychological tests hypothesized to measure temporal lobe functioning (visual perception—VP; peabody picture vocabulary test, third edition—PPVT-III) in 48 healthy children ages 5–18 years. After controlling for age and gender, left and right temporal and left occipital volumes were significant predictors of VP. Left and right frontal and temporal volumes were significant predictors of PPVT-III. Temporal volume emerged as the strongest lobar correlate with both tests. These results provide convergent and discriminant validity supporting VP as a measure of the "what" system; but suggest the PPVT-III as a complex measure of receptive vocabulary, potentially involving executive function demands.

1. Introduction

Ecological validity of pediatric neuropsychological assessment is considered the ability of laboratory tests to predict real-world functioning and/or to correlate with underlying brain structures. Although a few studies have examined the relationship between "real life" skills and intelligence (Kahn, 1992), attention (Price, Joschko, & Kerns, 2003), and executive functions (Isquith, Gioia, & Espy, 2004), there has been less focus on the relationship between these daily life skills and neuropsychological measurement of skills considered to be dependent on temporal lobe integrity (e.g., visual perception or receptive language skills).

Functional neuroimaging studies and research involving patients with known lesions or specific disorders have contributed to our understanding of temporal lobe functioning. Studies involving patients with lesions of the left temporal lobe (e.g., middle temporal gyrus, superior temporal gyrus, superior temporal sulcus, angular gyrus) have documented language comprehension deficits (Boatman, Lesser, & Gordon, 1995; Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004). Research with specific clinical populations (e.g., autism and dyslexia) has also documented temporal lobe abnormalities. Specifically in autism, a disorder characterized by primary deficits in language and social interaction, abnormalities in the function of the superior aspect of the temporal lobes have been identified (Abell et al., 1999; Boddaert et al., 2004; Meresse et al., 2005; Ohnishi et al., 2000; Zilbovicius et al., 2000). In healthy individuals a leftward asymmetry of the temporal lobe has been documented (Geschwind & Levitsky, 1968); whereas, in developmental dyslexia the volume of the temporal lobes has been shown to be symmetrical (Rumsey et al., 1986). Recent studies have not consistently found symmetrical temporal lobe volumes in dyslexic individuals, but have documented exaggerated asymmetries for those with dyslexia. Specifically, smaller left temporal lobe volumes, particularly in the planum temporale, and decreased overall temporal lobe volumes have been found when compared to control participants (e.g., Eliez et al., 2000; Hugdahl et al., 2003; Leonard et al., 1993; Vinckenbosch, Robichon, & Eliez, 2005). Similarly, neuroanatomical findings from Livingstone and colleagues indicate that poor readers have smaller lateral (LGN) and medial (MGN) geniculate nuclei (Galaburda & Livingstone, 1993; Livingstone, Rosen, Drislane, & Galaburda, 1991). In additional studies of language functioning in dyslexia, Tallal and colleagues have found difficulties in auditory and somatosensory processing of linguistic and nonlinguistic speech sounds (Tallal, 1980; Tallal & Katz, 1989; Tallal & Piercy, 1973; Tallal & Stark,

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1982; Tallal, Stark, & Mellits, 1985). These findings were later supported by Binder and colleagues (1994), who utilized functional magnetic resonance imaging (fMRI) of language functioning in healthy adults, and found that the superior temporal lobes are involved in decoding the acoustic signals of speech. Thus the left temporal lobe appears to be specialized for language processing, and is therefore crucial in a variety of school-related abilities including development of reading skills (Molfese & Molfese, 1986).

Functioning of the right temporal lobe is less well researched and its function is also not as clearly defined. Early studies have documented deficits in visual form discrimination following right temporal lobectomy (Meier & French, 1965) and right hemisphere missile wounds (Newcombe, 1969). The right superior temporal cortex is thought to process the 'what' in visual perception tasks (Ungerleider & Haxby, 1994). According to Goodale and Milner (1992; Milner & Goodale, 2008), there are two streams of visual processing: the dorsal "action" stream, projecting from early visual areas and the superior colliculus (via the pulvinar) to the posterior parietal cortex; and, the ventral "perception" stream, projecting from the retina to the lateral geniculate nucleus (pars dorsalis) in the thalamus, to primary visual cortex, and then to regions in the occipito-temporal cortex. The ventral stream is described to provide the detailed representations of the world that are required for cognitive processes including recognition, identification, and planning. There is increasing yet inconsistent evidence supporting a relationship between visual perception and other brain regions, particularly in the parietal lobe (Himmelbach & Karnath, 2005). Much of this evidence comes from early reports of patients with spatial neglect, which is a lack of awareness of space and object parts in the hemi-space contralateral to the brain lesion. From these early studies it has been believed that spatial neglect is associated with lesions of the right inferior parietal lobe and the temporal, parietal, and occipital lobe juncture (Heilman & Valenstein, 1972). In a study by Karnath, Ferber, and Himmelbach (2001), only patients with spatial neglect without visual-field defects were included, as it was felt that previous research may have been confounded by inclusion of those with visual-field impairments. Computed tomography (CT) or MRI scans revealed the lesions of these patients were predominantly in the superior temporal gyrus. As Karnath (2001) elucidated, the rostral portion of the superior temporal sulcus and superior temporal gyrus are located at the transition between the ventral "what/perception" and dorsal "where/action" streams of visual processing, which may account for mixed findings of temporal and parietal lobe involvement in object perception. Goodale and Milner (1992; Milner & Goodale, 2008) also note that the dorsal and ventral streams both process information about the structure and spatial location of objects. They further state that although this information is mediated by different pathways, the two systems are intimately connected with the response of one stream often contingent upon the complex mechanisms of the other stream.

Although previous pediatric neuroimaging research examining brain development in healthy children has been cross-sectional (Caviness, Kenney, Richelme, Rademacher, & Filipek, 1996; Courchesne et al., 2000; Giedd et al., 1996; Jernigan, Trauner, Hesselink, & Tallal, 1991; Pfefferbaum et al., 1994; Reiss, Abrams, Singer, Ross, & Denckla, 1996), Giedd and colleagues (1999) published longitudinal data in which linear increases in white matter volume with age were observed, whereas age-related changes in gray matter were nonlinear and regionally specific. Particularly, frontal lobe gray matter volumes increased during pre-adolescence, peaked around 12 years of age for boys (11 years of age for girls), and declined during post-adolescence resulting in an overall net decrease across the age span (i.e., 4–20 years). Results were similar for parietal lobe volumes and differed only in that the slope of the curve was steeper and volumes peaked one year earlier for each gender. In contrast, temporal lobe volumes peaked around 16 years of age for both boys and girls with a mild decline thereafter. Occipital lobe gray matter followed a linear increase over the age range with no evidence of decline or plateau. Total cerebral gray matter volume was approximately 10% larger in boys and peaked slightly earlier in girls, but the shapes of the curves were similar for both genders.

While studying patients with known brain lesions has led to advances in the study of brain–behavior relationships, fewer studies have documented an association between regional brain volumes and neurobehavioral function in healthy children. Recently, Shaw and colleagues (2006) investigated the relationship between intellectual functioning and cortical development. They found a negative correlation between IQ and cortical thickness in young children, suggesting that timing and trajectory of changes in gray matter volume are associated with efficiency of cognitive functioning. That is, in young children, higher IQ was associated with thinner cortex, particularly in the frontal and temporal lobe regions; however, this relationship reversed in late childhood, with positive correlations observed between cortical thickness and IQ. Interestingly, children with superior IQ had thinner superior prefrontal cortex at an early age, with a rapid increase in cortical thickness peaking at age 13, and attenuating into late adolescence.

In healthy individuals, studies have documented a modest relationship between total brain volume and intellectual functioning (Reiss et al., 1996; Schoenemann, Budinger, Sarich, & Wang 2000; Willerman, Schultz, Rutledge, & Bigler, 1991). In contrast, research examining correlations between *specific* neuropsychological tests and regional brain volumes in healthy individuals are limited (Egan et al., 1994). Studies involving individuals with temporal lobe damage have implicated the temporal lobes in auditory sensation and perception; selective attention for auditory and visual stimuli; visual perception; organization and categorization of verbal material; language comprehension; long-term memory; personality and affective behavior; and, sexual behavior (Kolb & Wishaw, 1990). Volumetric MRI studies with temporal lobe epilepsy patients have been successful in documenting a correlation between hippocampal volume and verbal memory performance (e.g., Pegna et al., 2002; Reminger et al., 2004) and amygdalar volumes have been correlated with visuospatial memory (e.g., Pegna et al., 2002).

The purpose of the present study was to determine whether regional temporal lobe volumes would predict performance on two neuropsychological tests hypothesized to measure temporal lobe functioning in a sample of healthy children. Specifically, we hypothesized that, after consideration of age, gender, and total cranial volume, right temporal lobe gray matter volume would be the best predictor of performance on a test of visual object perception and left temporal lobe gray matter volume would be the best predictor of performance on a test of receptive vocabulary.

2. Materials and methods

2.1. Participants

Forty-eight typically developing children ages 5–18 years (24 boys) were recruited from the Baltimore, MD area by advertisement. Each participant and parent signed a consent form that met the institutional review board standards of the Johns Hopkins Medical Institutions. Participants were initially screened over the telephone and excluded if there was a history of neurological disorder, mental retardation, or learning disability. Parents of those children meeting this eligibility criterion participated in a structured diagnostic interview using the diagnostic interview for children and adolescents—fourth edition (DICA-IV; Reich, Welner, & Herjanic, 1997), which is based on the diagnostic and statistical manual of mental disorders—fourth edition (DSM-IV; American Psychiatric Association, 1994). Children meeting DSM-IV criteria