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Research Report

Left-handedness and language lateralization in children

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ABSTRACT

This fMRI study investigated the development of language lateralization in left- and right-handed children between 5 and 18 years of age. Twenty-seven left-handed children (17 boys, 10 girls) and 54 age- and gender-matched right-handed children were included. We used functional MRI at 3 T and a verb generation task to measure hemispheric language dominance based on either frontal or temporo-parietal regions of interest (ROIs) defined for the entire group and applied on an individual basis. Based on the frontal ROI, in the left-handed group, 23 participants (85%) demonstrated left-hemispheric language lateralization, 3 (11%) demonstrated symmetric activation, and 1 (4%) demonstrated right-hemispheric lateralization. In contrast, 50 (93%) of the right-handed children showed left-hemispheric lateralization and 3 (6%) demonstrated a symmetric activation pattern, while one (2%) demonstrated a right-hemispheric lateralization. The corresponding values for the temporo-parietal ROI for the left-handed children were 18 (67%) left-dominant, 6 (22%) symmetric, 3 (11%) right-dominant and for the right-handed children 49 (91%), 4 (7%), 1 (2%), respectively. Left-hemispheric language lateralization increased with age in both groups but somewhat different lateralization trajectories were observed in girls when compared to boys. The incidence of atypical language lateralization in left-handed children in this study was similar to that reported in adults. We also found similar rates of increase in left-hemispheric language lateralization with age between groups (i.e., independent of handedness) indicating the presence of similar mechanisms for language lateralization in left- and right-handed children.

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1. Introduction

Handedness is a characteristic human trait. Even in our closest genetic relatives hand preference is not pronounced. In chimpanzees, 800 trials per participant of reaching for food revealed that 9/30 (30%) were using right hand ≥90% of the time, 9/30 (30%) were using left hand ≥90% of the time, and the remainder of the group was "ambidextrous" (Finch, 1941). The finding of equal distribution of handedness in chimpanzees has been recently questioned by others (e.g., Corballis, 2009; Hopkins and Leavens, 1998; Hopkins et al., 2007; Hopkins and Nir, 2010). Even so, the results of handedness evaluations appear to be consistent only in humans hence hand/extremity preference, while likely not an uniquely human feature, is consistently present only in the human race with approximately 90% of us reporting right hand preference (Gilbert and Wysocki, 1992) with this trait already present in 18 month old infants (Suzuki et al., 2009).

Genetically-determined and already present in chimpanzees (Hopkins and Nir, 2010) brain asymmetry may be the reason for language and auditory cortex asymmetries that emerge during prenatal and early postnatal human development (Chi et al., 1977; Hill et al., 2010) and that have been noted on the structural and functional levels in many adult studies published to date e.g., (Foundas et al., 1994; Penhune et al., 2003; Rademacher et al., 2001; Smith et al., 2011; Tzourio-Mazoyer et al., 2010b). Research provides evidence for the existence of a connection between familial sinistrality, personal handedness, cortical and subcortical asymmetries and language lateralization which could be linked by a common genetic factor or factors underlying the hemispheric organization of language and motor functions. Previous functional imaging studies have found a connection between familial left-handedness and hemispheric lateralization of language in adults (Hecaen et al., 1981; Szaflarski et al., 2002; Tzourio-Mazoyer et al., 2010a). However, while handedness appears to be at least partially mediated by genetic factors, a number of environmental, developmental and pathological factors have been shown to influence the presence and the degree of atypical handedness (Domellof et al., 2009; Francks et al., 2007; Hecaen and Sauguet, 1971; Hecaen et al., 1981; Lust et al., 2010; Springer et al., 1999; Staudt et al., 2002; Tillema et al., 2008; Yuan et al., 2006).

Handedness might be expected to provide an indicator of cerebral hemispheric language dominance (Geschwind and Galaburda, 1985). In general, two types of handedness are usually measured—personal and familial. Their effects on cortical and subcortical anatomy and function may be different (Tzourio-Mazoyer et al., 2010b). As discussed above, anatomical studies have shown that there are asymmetries in planum temporale and that these asymmetries are more pronounced in the right- when compared to the left-handed individuals (Foundas et al., 1995; Steinmetz et al., 1991). The extent of such asymmetries may be related to the presence or absence of familial handedness (Tzourio-Mazoyer et al., 2010b). As shown recently, these asymmetries may be, in part, related to "brain torque" (leftward frontal rightward occipital asymmetry) (Barrick et al., 2005). It has also been suggested that these anatomical asymmetries may be one of the reasons for left-hemispheric language dominance (Foundas et al., 1994; Steinmetz et al., 1991). Noninvasive fMRI studies of healthy adults (Pujol et al., 1999; Springer et al., 1999) have demonstrated that approximately 95% of right-handed adults have left hemispheric dominance for language. Similar findings were reported by authors using other non-invasive techniques to determine language lateralization e.g., transcranial Doppler ultrasonography (Knecht et al., 2000a,b). A gradual decrease in the strength of left-hemispheric language lateralization with decreasing right-handedness (or increasing left-handedness) has also been noted with up to 27% of strong left-handers having right-hemispheric language representation (Knecht et al., 2000b). Similar findings of approximately 25% atypical language representation (symmetric or right-hemispheric) were reported in fMRI studies conducted in healthy left-handed adults (Pujol et al., 1999; Szaflarski et al., 2002). The strength of language lateralization may be further modulated by multiple factors including age (Holland et al., 2001; Szaflarski et al., 2006a, 2006b), presence of familial sinistrality (Hecaen et al., 1981; Szaflarski et al., 2002; Tzourio-Mazoyer et al., 2010a), or brain/head size (Josse et al., 2006; Ringo et al., 1994; Tzourio-Mazoyer et al., 2010a).

While the above (and other) studies examined the relationship between handedness and language lateralization in right- and left-handed adults, normative neuroimaging data in the pediatric population are less readily available (Everts et al., 2009; Haag et al., 2009; Holland et al., 2001, 2007; Ressel et al., 2008). In 2011, we were not able to identify any studies that specifically focused on the neuroimaging of language lateralization in left-handed children and adolescents. Currently, there is evidence that left hemispheric dominance for language is present in 3 month old infants and that it continues to develop in pre-literate children (Dehaene-Lambertz et al., 2002; James, 2010). Studies such as these have also found that the left hemispheric contribution to language processing in right-handed individuals increases throughout childhood (Everts et al., 2009; Holland et al., 2001, 2007; Szaflarski et al., 2006a). Further, early studies of language development showed an association between language dominance and handedness and/or eye preference (Belmont and Birch, 1965; Benton and Kemble, 1960) and that non-right-handedness correlates with atypical language development, especially in patients with neurologic illness such as epilepsy (Binder et al., 1996; Kim et al., 2011; Woods et al., 1988; Yuan et al., 2006) or stroke (Jacola et al., 2006; Staudt et al., 2001; Tillema et al., 2008). But, to date, large-scale neuroimaging studies examining the left-hemispheric contributions to speech production taking into consideration the effects of personal and/or familial handedness and/or head size on cortical language distribution in left-handed children have not been conducted.

Therefore, the goal of this study was to establish the frequency of atypical language lateralization (symmetric or right-hemispheric) in a sample of left-handed children with familial history of left-handedness and compare them to age and gender matched right-handed children with or without family history of left-handedness. Based on previous studies of adults, we hypothesized that left-handed children (with family history of left-handedness) would have a higher proportion of bilateral and right-hemisphere dominant language