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Handedness, dichotic-listening ear advantage, and gender effects on planum temporale asymmetry—A volumetric investigation using structural magnetic resonance imaging

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Abstract

Previous research has often examined whether the asymmetrical structure of the planum temporale (PT) represents an anatomical correlate of lateralized language-processing functions, gathering diverging empirical evidence by comparing PT asymmetry in subjects with differing handedness, gender, or speech lateralization. Apart from other methodological problems, direct comparisons between studies are hampered by insufficient assessment and consideration of all three potential determinants of structural cerebral asymmetry.

Based on volumetric assessment of structural Magnetic Resonance Imaging (MRI) scans of 104 healthy subjects, the present study replicated earlier observations of an overall leftward PT asymmetry, which was found to prevail irrespective of handedness, gender, or dichotic-listening ear advantage. However, the mean magnitude of this leftward asymmetry was not determined by either one of these factors in itself, but varied depending on their specific combination. A clear correspondence between structural and functional asymmetry was only observed among right-handed males. In this particular subgroup, more pronounced structural asymmetry was associated with an enlarged PT on the left side, while the enhanced leftward asymmetry of female sinistrals resulted from smaller adjusted volumes of their right PT.

The existence of such complex interactions suggests that future research in this area can only be expected to overcome past inconsistencies by adequately considering handedness, gender, **and** speech lateralization.

Keywords: Handedness; Functional lateralization; Sex effects; Structural asymmetries; Planum temporale; Magnetic resonance imaging

1. Introduction

The planum temporale (PT) is a roughly triangular region on the posterior surface of the temporal lobe (von Economo & Horn, 1930), posterior to the primary auditory field located in the first (anterior) transverse temporal gyrus (Heschl's gyrus) in the depth of the Sylvian fissure. It constitutes a portion of Brodmann area 22 (Doherty, Meredith, Farrell, Toland, & Staunton, 1999) and includes part of Wernicke's area posteriorly (Foundas, Leonard, & Heilman, 1995). The PT is not a plane, but a three-dimensional convoluted structure, and there have been continuing debates about the precise delineation of its boundaries (Zetzsche et al., 2001).

The presence of a larger PT in the left hemisphere was first shown by Pfeifer (1920) and von Economo and Horn (1930), but only confirmed and quantified decades later by Geschwind and Levitsky (1968) in a post-mortem study of 100 brains. They found that the left PT was larger in 65% and the right PT was larger in 11% of the measured brains, while symmetrical PTs were seen in approximately 24%. Based on these observations and the known preponderance of left-hemisphere lateralization of verbal functions, the authors proposed a structure–function relationship between

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PT asymmetry and language processing. Ever since, the role of this anatomical region has raised great theoretical and practical interest in basic neuroscience and clinical neuropsychology (cf. Galaburda, LeMay, Kemper, & Geschwind, 1978a, as well as the review by Beaton, 1997).

The leftward asymmetry was subsequently replicated in further post-mortem investigations (Kopp, Michel, Carrier, Biron, & Duvillard, 1977; Wada, Clarke, & Hamm, 1975; Witelson & Pallie, 1973). These early reports were merely based on length or area measurements, and information on sex, handedness, or speech lateralization was not always available.

In recent years, computer tomography (CT), magnetic resonance imaging (MRI), and other brain-imaging techniques have allowed in vivo assessment of PT length, PT area, and PT volume measures. Using a multitude of methodological approaches, such newer findings confirmed the overall left-oriented asymmetry, but showed that it is subject to substantial interindividual variability (e.g., Karbe et al., 1995; Watkins et al., 2001).

When Steinmetz, Volkmann, Jäncke, and Freund (1991) considered effects of handedness on anatomic measures, the leftward PT asymmetry was observed in right-handers (RH) as well as in the left-handed (LH) group, but was more pronounced in the RH subjects. Subsequent studies replicated this lower degree of leftward PT asymmetry in LH (Foundas, Leonard, & Hanna-Pladdy, 2002; Jäncke, Schlaug, Huang, & Steinmetz, 1994).

However, other observations suggested that many related findings may have been an artefact of the increased likelihood of right-hemisphere speech dominance in left-handers (Foundas, Leonard, Gilmore, Fennell, & Heilman, 1994; Moffat, Hampson, & Lee, 1998). Thus, PT asymmetry could be associated with language lateralization rather than with handedness per se.

Initially, only indirect evidence for this notion was provided by the combined consideration of several aspects: following an early observation by Rasmussen and Milner (1977) that over 95% of the RH but only about 70% of the LH show leftward language lateralization, the direction of this general association between handedness and functional speech lateralization was confirmed by more recent reports (e.g., Annett & Alexander, 1996; Knecht et al., 2000), although the exact percentages varied from one study to another depending on the composition of the investigated samples and other methodological details.

PT coincides with part of Wernicke's area on the left side, lesions of which commonly result in Wernicke's aphasia (Galaburda, Sanides, & Geschwind, 1978b). Using functional MRI (fMRI), the PT has been shown to play a major role in auditory processing and learning (Griffiths & Warren, 2002; Jäncke, Gaab, Wüstenberg, Scheich, & Heinze, 2001). Moreover, PT asymmetry is apparent by the 29th to 31st weeks of gestation, hence abnormalities in this brain region may suggest a disruption of neurodevelopmental processes involved in establishing functional hemispheric lateralization (Chi, Dooling, & Gilles, 1977). Thus, the general hypothesis advanced by Geschwind and Levitsky (1968) claiming that structural PT asymmetry is related to functional speech-processing asymmetries has received support from many different areas of investigation.

Varying results have been reported when this relationship was further examined. Direct evidence was provided by Foundas et al. (1994), who compared the anatomy of the PT with speech lateralization assessed using the Wada test. They found that all subjects with leftward PT asymmetry had their speech functions lateralized to the left hemisphere, while the only subject with right > left PT asymmetry showed right-hemisphere speech functions. Obviously, these findings must be interpreted with caution because, in the investigated sample, all subjects with left-hemisphere speech lateralization were RH, whereas the single case with right-hemisphere speech functions was a non-RH.

However, the association between functional language lateralization and structural PT asymmetry was not always replicated. When Jäncke and Steinmetz (1993) correlated laterality indices of four verbal dichotic tests with the degree of anatomical PT asymmetry, none of these correlations attained statistical significance. Additionally, they found no difference in degree of PT asymmetry between subjects with right-ear advantage (REA, indicating left-hemisphere speech functions) and those with left-ear advantage (LEA) in the administered dichotic-listening tasks.

Likewise, divergent results have also been obtained with respect to possible sex differences in structural PT asymmetry. Applying a variety of methodological approaches and definitions, some researchers have reported reduced PT asymmetries in women as compared to men (Good et al., 2001; McGlone, 1980; Wada et al., 1975), whereas no such gender differences in PT asymmetry were observed by others (Habib, Robichon, Lévrier, Khalil, & Salamon, 1995; Jäncke et al., 1994; Kopp et al., 1977).

In summary, many studies have examined and detected associations between handedness, speech lateralization, gender, and PT asymmetry, but to our knowledge it has not yet been analysed how all three of these often confounded factors may interact in their effects on the variability of this anatomical structure. For example, although Jäncke and Steinmetz (1993) assessed all three variables, they only analysed the influence of handedness and language lateralization on PT asymmetry. On the other hand, Moffat et al. (1998) examined the relation between behavioural laterality (handedness and speech lateralization) and structural laterality only in men, not in women.

Turning to the issue of possible causes underlying structural brain asymmetries, one crucial question demands whether such asymmetry results from enlargement on one side or a reduction in size on the other side. It has been proposed that the language system and its anatomical correlates, including the PT, may develop asymmetrically in utero (i.e., being initially larger on the left side), but that later epigenetic effects acting during early development and infancy could