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Variability in perisylvian brain anatomy in healthy adults

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Abstract

Gray matter volumes of Heschl's gyrus (HG), planum temporale (PT), pars triangularis (PTR), and pars opercularis were measured on MRI in 48 healthy right-handers. There was the expected leftward PT asymmetry in 70.8%, and leftward PTR asymmetry in 64.6% of the sample. When asymmetry patterns within individuals were examined, there was not one typical pattern, rather several typical configurations were found. In addition, some combinations of asymmetry did not exist in our sample suggesting that some perisylvian anatomical configurations may provide a more suitable neural substrate for the development of language than others. There were also sex differences in HG. Men had rightward asymmetry and women demonstrated leftward asymmetry, due to women having smaller right HG, compared to men.

Keywords: Planum temporale; Heschl's gyrus; Broca's area; Asymmetry; Language; Sex differences; MRI

1. Introduction

Perisylvian regions critical for language functions include posterior language regions, the planum temporale (PT) and Heschl's gyrus (HG) and anterior or frontal language areas, the pars triangularis (PTR) and the pars opercularis (POP). The purpose of this study was to examine the anatomy of perisylvian language areas in a large sample of neurologically intact healthy right-handed adults. Gray matter volumes of anatomical regions of interest (ROIs) were examined using reliable and validated volumetric MRI methods of stringently defined functional regions. These ROIs included posterior perisylvian language regions (HG, PT) and anterior speech-language areas (PTR, POP). Although there are studies, which have examined the anatomy of some of these language areas, there are not studies that have examined gray matter volume of all of these perisylvian language regions (HG, PT, PTR, POP) within individuals in a large sample of healthy right-handed adults. It is important to study the anatomy of these regions in a large sample of healthy right-handers in order to determine what anatomical configurations are considered typical or more common. It is also important to determine what anatomical configurations are less common in a healthy sample of adults. If we have a better understanding of the proportion of healthy individuals with typical versus atypical perisylvian anatomy, then we can generate cognitive-anatomical models that will allow us to study neurodevelopmental speech and language disorders, such as developmental stuttering, dyslexia, and specific language impairment. It is also important to examine multiple regions within individuals and look at combined configurations. Although a few studies have examined these brain regions in individuals with neurodevelopmental disorders, there are very few volumetric MRI studies involving large samples of healthy adults, limited to

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right-handers. This study also differs from prior studies in that gray matter volume of the full extent of each region was measured. All brains were maintained in real space and measurements were made using a cursor-driven mouse, as opposed to automated segmentation. Sex differences were also examined in this study and brain size was controlled.

The PT (Brodmann's area, BA 22) is comprised of auditory association cortex (Galaburda, 1995) and is important in higher order auditory speech processing, such as phonological decoding (Foundas, 2001). The PT comprises a portion of the classic Wernicke's area, which is important for auditory comprehension. The anatomy of this region has been extensively studied, with consistent evidence that the size of the left PT is larger than the right PT size (for review, Shapleske, Rossell, Woodruff, & David, 1999) with this leftward planar asymmetry present in 70–75% of human brains, regardless of the measurement technique utilized. This anatomical asymmetry has been found in both postmortem and MRI studies and in studies utilizing length, surface area, and volume measurements (for review, Shapleske et al., 1999). In addition, structural asymmetries of the PT at the microscopic level have been demonstrated. Temporal auditory area (area TA1 or Tpt) which includes part of the PT and posterior superior temporal gyrus (pSTG) has been measured and similar to the studies of gross anatomy, these studies have found this region to be larger in the left hemisphere, compared to the right (Galaburda & Sanides, 1980; Galaburda, Sanides, & Geschwind, 1978).

HG (BA 41/42) contains primary auditory cortex (Galaburda & Sanides, 1980; Rademacher, Caviness, Steinmetz, & Galaburda, 1993; Wallace, Johnston, & Palmer, 2002) and is important for elemental auditory processing. HG anatomy has not been as extensively studied as the PT and consistent asymmetries have not been established. Some studies have found that HG is larger in the left hemisphere, compared to the right (Dickey et al., 2002; Hirayasu et al., 2000; McCarley et al., 2002; Musiek & Reeves, 1990; Rojas, Teale, Sheeder, Simon, & Reite, 1997). Other studies, however, have found a larger right HG than left (Campain & Minckler, 1976). Still other studies have not found any anatomical asymmetries of HG (Kulynych, Vladar, Jones, & Weinberger, 1994; Penhune, Zatorre, MacDonald, & Evans, 1996). Some of these discrepancies may be due to different ways of defining and measuring the structure. HG length, surface area, white matter volume, and gray matter volume have been measured, depending on the study. In addition definitions of the boundaries of HG have varied across studies. Cytoarchitectonic studies of HG have also demonstrated variable results. Rademacher et al. (1993) measured BA 41 and found a leftward asymmetry and another study found a leftward asymmetry of the most granular part of BA 41 (von Economo and Horn, 1930, cited in Rademacher et al., 1993). Galaburda and Sanides (1980), however, found variable asymmetry of primary auditory cortex in 3 brains. Another study showed that left BA 41 was larger than the right in men, but found a lack of asymmetry in women (Rademacher, Morosan, Schleicher, Freund, & Zilles, 2001).

The PTR (BA 45) contains heteromodal association cortex (Hayes & Lewis, 1993, 1995) and is involved in higher order speech and language functions, such as semantics and syntax. The POP (BA 44) is comprised of motor association cortex (Hynd and Cohen, 1993, cited in Foundas, 2001; Mesulum, 2000, cited in Foundas, 2001) and is important for articulation and motor aspects of speech. The PTR and POP together comprise the classic Broca's area. When the PTR and POP have been measured together on postmortem brains, a leftward asymmetry has been found in about 60–75% of human brains (Albanese, Merlo, Albanese, & Gomez, 1989; Falzi, Perrone, & Vignolo, 1982). These structures have also been measured separately in volumetric MRI studies, with the left PTR larger than the right in about 70–88% of right-handers (Foundas, Browning, & Weinberger, 1998; Foundas, Leonard, Gilmore, Fennell, & Heilman, 1996; Foundas, Leonard, & Heilman, 1995; Foundas, Weisberg, Browning, & Weinberger, 2001; Gauger, Lombardino, & Leonard, 1997) and with a leftward POP asymmetry in 56% of right-handers (Foundas et al., 1998). Not all studies, however, have found a structural asymmetry of the POP (Tomaiuolo et al., 1999). These discrepancies may be due to differences in measurement technique, as the Tomaiuolo et al. study measured gray matter volume and included the diagonal sulcus in their POP measure, whereas other studies (Foundas et al., 1998) have used surface area measures and excluded the diagonal sulcus.

Sex-linked differences in the anatomy of some of these language areas have also been suggested. A few studies have found that women, compared to men, have a reduced leftward PT asymmetry (Kulynych et al., 1994; Shapleske et al., 1999; Wada, Clarke, & Hamm, 1975; Wisniewski, 1998). There is controversy, however, as not all studies have found sex differences in PT anatomy (Jäncke, Schlaug, Huang, & Steinmetz, 1994; Steinmetz, 1996). Other studies have found that females, compared to males, have smaller right PT size, resulting in a stronger leftward PT asymmetry in females (Knaus, Bollich, Corey, Lemen, & Foundas, 2004; Preis, Jäncke, Schmitz-Hillebrecht, & Steinmetz, 1999). In postmortem brains, Harasty, Double, Halliday, Kril, and McRitchie (1997) found that PTR, POP, and pars orbitalis volumes were proportionally larger in women, compared to men. Another study, utilizing volumetric MRI, found a leftward PTR asymmetry in both men and women, but the magnitude of this asymmetry was reduced in women (Foundas et al., 1998). For the POP, there was a leftward asymmetry in men and no interhemispheric size difference in women. Women were also more likely to have an atypical rightward POP asymmetry. Functional neuroimaging studies have also indicated potential sex differences within the language system as several studies have found that men have left lateralized