Website publication 11 March 1998

NeuroReport 9, 829–833 (1998)

Left planum temporale surface correlates with functional dominance during story listening*

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THE relationship between anatomical asymmetry of the planum temporale (PT) and functional lateralization for language comprehension was studied in 14 normal volunteers, including five left-handers (LH). PT surfaces and asymmetry were measured in each subject using structural MRI, while functional lateralization was assessed on individual regional cerebral blood flow (rCBF) difference images of a PET-$H_2^{15}O$ activation protocol in which a story listening condition was contrasted with a control state. Significant positive correlations were found between the left PT surface and the amount of NrCBF increase during the story listening in the left superior temporal gyrus as well as with the left-right activation index in the superior temporal and the temporal pole. Functional imaging data were correlated neither with the right PT surface nor with the right–left PT surface asymmetry index. However the latter index was correlated with handedness scores. The present results indicate that the size of the left PT is the relevant anatomical landmark for language dominance, and demonstrate that anatomical asymmetries are part of the functional variability for language *NeuroReport* 9: 829–823 © 1998 Rapid Science Ltd.

Key words: Comprehension; Dominance; Handedness; Language; PET; Planum temporale; Speech; Temporal cortex

Introduction

Since the discovery by Geschwind of a planum temporale (PT) asymmetry favoring the left hemisphere in right-handers (RH),[1] several imaging studies have confirmed this result using *in vivo* MRI.[2] The concurrent absence of PT asymmetry in left-handers (LH)[3] reinforced Geschwind's seminal hypothesis that this asymmetry could be the basis for the functional dominance for language. Additional arguments were obtained from the study of dysphasics who present decreased asymmetries of the left perisylvian region[4] associated with a deficit in processing of a rapid tones sequence.[5] This language developmental pathology was thus thought to be linked to a defect in left hemisphere dominance, with the PT as a candidate region, since this auditory associative area is implicated in the early processing of sounds[6–8] and in selective auditory attention.[9,10]

Despite these converging but indirect pieces of evidence, the hypothesis that PT asymmetry is a reflect of left hemisphere dominance for language remains to be formally validated. A first attempt to correlate anatomical asymmetries directly with functional dominance was conducted by Jäncke but failed to demonstrate a correlation between the PT asymmetry and auditory lateralization as measured by dichotic listening tasks,[11] leading the investigators to conclude that functional auditory lateralization for language and PT asymmetry were not correlated.

Within this framework, functional neuroimaging could be the method of choice for investigating the existence of such a correlation for it allows a direct comparison between anatomical and functional asymmetries. As a matter of fact, in a previous PET activation study we have shown that, when RH subjects listen to factual stories in mother tongue, they activate a network of temporal and frontal regions, with significant asymmetries favoring the left hemisphere[12] and most likely reflecting the left hemisphere functional dominance for language comprehension. We studied five additional subjects, selected as left-handers, during the same story listening task, and compared their temporal cortex activations with those of the RH group. Pooling the RH and LH subgroups, we then tested Geschwind's

*This work was presented in part at the Third International Conference on Functional Mapping of the Human Brain, Copenhagen, May 19–23, 1997.

hypothesis, searching for correlation between PT surfaces defined on subject individual MRI, and functional dominance for language comprehension measured by individual temporal cortex PET activation measurements.

Subjects and Methods

Subject selection: The normal volunteers were five left-handed and nine right-handed French healthy male graduate medical students, all having French as their mother tongue (age 24 ± 2.2 years, mean ± s.d.). Their handedness was assessed using the Edinburgh inventory,[13] on a scale ranging from –100 (exclusive use of right-hand) to +100 (exclusive use of left hand). All RH scores were > 66, while LH scores were below –6 (see Table 1). The subjects were free from cerebral abnormalities as assessed by their MRI brain scans. The study was approved by the Atomic Energy Commission Ethics Committee and all subjects gave their written informed consent.

Task design: In the 'Story' condition, the 15 subjects were instructed to passively but attentively listen to factual stories in French, originally designed for the RH protocol,[12] that were emotionally rich and taken from recent events. The different stories used for the replications were read by the same female speaker with comparable pitch, intonation, and volume, each story lasting about 2.5 min. Stories were presented binaurally over earphones, starting 45 s before water injection. After listening to stories, subjects were asked questions to ensure that they understood the stories and thus paid attention to the task. A 'Rest' condition served as a reference, which consisted of resting silently with eyes closed without any particular instruction except to relax. All examinations were performed in total darkness.

Table 1. Edinburgh questionnaire lateralization score, planum temporale (PT) surfaces and PT anatomical laterality index (ALI = (right PT – left PT)/2(right PT + left PT)) measured in the 14 subjects.

Subjects	Edinburgh score	Right PT (mm^2)	Left PT (mm^2)	ALI
RH1	75	305.9	605.0	–0.65
RH2	75	578.6	928.9	–0.46
RH3	100	317.8	583.3	–0.58
RH4	100	1048.9	705.7	0.39
RH5	81	273.7	562.2	–0.69
RH6	81	394.6	281.4	0.33
RH7	100	308.7	394.0	–0.24
RH8	100	150.3	495.4	–1.06
RH9	66	425.6	487.9	–0.13
Mean (s.d.)	70.5 (6.3)	422 (262)	560 (185)	–0.34 (0.48)
LH1	–67	463.1	534.5	–0.14
LH2	–83	433.5	508.9	–0.16
LH3	–100	831.1	547.3	0.41
LH4	–83	452.3	293.6	0.42
LH5	–8	399.1	436.7	–0.09
Mean (s.d.)	–68.2 (35.6)	515 (177)	464 (104)	0.089 (0.30)

Data acquisition: Using PET and $H_2^{15}O$, normalized regional cerebral blood flow (NrCBF) was repeatedly measured either twice (RH subjects) or three times (LH subjects) during both conditions, giving 20 and 15 pairs of measurements in each group, respectively. The order of condition presentation was randomized by block. Two different PET cameras were used for each group, a time-of-flight PET system[14] giving seven brain slices of 9 mm thickness every 12 mm with an in-plane resolution of 5 mm for right-handers, and an ECAT 953B/31 camera giving 31 contiguous brain slices of 3.375 mm thickness with an in-plane resolution of 5 mm[15] for left-handers. All emission data were acquired in 2D mode. In both cases, following the i.v. injection of a bolus of 60 mCi $H_2^{15}O$, a single 80 s scan was reconstructed (including a correction for head attenuation using a measured transmission scan) with a 0.5 mm^{-1} cut-off frequency Hanning filter. The interval between two injections was 15 min.

Prior to the PET experiment, each subject underwent magnetic resonance imaging (MRI) T1-weighted acquisition providing a set of 3 mm contiguous axial slices covering the whole brain, this MRI brain volume being later aligned with the subject PET $H_2^{15}O$ volumes.

Image analysis: A 3D reconstruction of axial MRI slices that allows reslicing of the volume in any plane (Voxtool General Electric, Buc, France) was used to measure the PT surface of each hemisphere on a slice passing through the sylvian fissure.[16] PT limits were identified according to the rules described by others.[17–19] The PT anterior border, corresponding to the posterior sulcus of Heschl's gyrus, was identified using its typical shapes on both axial, coronal and sagittal slices.[20] When the posterior sulcus of the transverse temporal gyrus did not intersect the lateral border, we extended it following its general direction.[19] In any case, when a supplementary transverse gyrus was present, it was considered, whatever the side, to belong to PT.[2,17] The posterior limit of the PT, corresponding to Sylvius posterior ascending branch, was defined on sagittal slices. Its internal limit was identified as the retro-insular point where the anterior and posterior limits met, showing a triangular shape. Using these landmarks, a single operator delineated the PT region in every subject MR, allowing the PT surface to be computed. The entire measurement process was replicated by the same operator and the PT surface was eventually defined as the mean of the two measurements: the average of absolute variations between two replicates was 42.7 (9%) and 39.5 (6%) mm^2 for the right and left PT, respectively, in very close agreement with previously published reproducibility figures for PT surface manual definition.[16] Finally, an anatomical lateralization index (ALI) was computed for each of the 14 subjects as: ALI = (right PT – left PT)/0.5 (right PT + left PT).[21]

Our PET image analysis method, which has been detailed elsewhere,[22] aims at computing cerebral blood flow in cerebral structures having MRI defined anatomical boundaries. In the present study, the analysis was focused on three such structures of interest in the temporal cortex of each hemisphere: first, the temporal pole, corresponding to Brodmann's area 38, was defined as the most anterior part of the superior temporal gyrus, limited posteriorly by the anterior commissure (AC) plane; second, the superior temporal gyrus encompassed the entire superior temporal gyrus but the temporal pole, therefore including Heschl gyrus and the PT, but was limited posteriorly by Sylvius ascending branch, excluding thus the supramarginalis gyrus; third, the middle temporal gyrus including the whole middle temporal gyrus but excluding the angular gyrus. In order to split the temporal and parietal cortices in this area reliably, the upper limit of the middle temporal gyrus was defined using a line parallel to the AC-PC plane starting at the origin of the ascending Sylvius.

Within each such anatomical volume of interest (AVOI), NrCBF was estimated during each condition as the ratio (in percent) of the radioactivity concentration in the AVOI to that of the whole brain, its variation between Story and Rest being defined as the AVOI activation. In each AVOI, activation significance was tested to 0 in both groups using Student's *t*-tests.

Correlation analysis: A functional lateralization index was defined for each AVOI and for each subject as the difference between the left and right AVOI activation. Linear regression analyses were used to study the relationships between handedness, given by the Edinburgh inventory score, anatomical lateralization assessed by either PT surfaces or ALI, and functional lateralization measured by either AVOI activation or functional activation index.

Results and Discussion

Handedness and anatomical measurements: There was no significant difference between the PT surfaces of the RH and LH groups. However, their ALI indices were significantly different ($p = 0.047$, one-tailed unpaired *t*-test), the left PT of RH subjects being larger than their right counterpart while the opposite result held in LH. No significant correlation was found between handedness scores and PT absolute surfaces; however, the correlation between handedness and ALI reached significance ($r = 0.48$, $p = 0.035$, df = 12, one-tailed r test).

An association between hand preference and gross lobar asymmetries has been previously described,[23] as well as between handedness and a PT asymmetry index.[3] The present study confirms these data: the more asymmetrical the PT, the more right-handed the subject, indicating that the PT asymmetry could be correlated with left hemisphere language dominance as previously suggested by numerous authors.[1,3]

Blood flow measurements (see Table 2): The contrast between the Story and Rest conditions revealed significant activations in both groups, bilaterally in the temporal pole and superior temporal gyrus as well as in the left middle temporal gyrus. A significant between-group difference was observed in the right middle temporal where a significant activation was present in LH only. In addition, significant between-group differences in functional lateralization index were observed in the temporal pole and the superior temporal cortex, almost reaching significance in the middle temporal region. In the temporal pole and superior temporal AVOI, functional lateralization index differences were due to a decreased asymmetry in the LH group caused by higher activations in their right hemisphere regions, although smaller leftward NrCBF increases were also observed. In the middle temporal cortex, the between

Table 2. Story minus Rest activation (%) in the temporal anatomical volumes of interest and right minus left activation indices in the Story minus Rest comparison in the AVOIs.

AVOI	Story versus Rest: activations		
	Right-handers	Left-handers	Group comparison (p value)
R TP	6.4 ± 3.0**	8.7 ± 5.0**	0.90
L TP	10.4 ± 5.1**	9.1 ±4.0**	0.44
R ST	5.7 ± 2.8**	6.8 ± 2.7**	0.86
L ST	9.7 ± 2.3**	8.3 ± 1.8**	0.10
R MT*	–0.8 ± 1.7	2.3 ± 3.0*	0.03
L MT	4.4 ± 3.2*	4.9 ± 3.6**	0.91
Left minus right activation in Story – Rest			
TP	4.0 ± 4.4**	0.4 ± 5.1	0.03
ST	4.0 ± 3.9**	1.5 ± 3.0	0.05
MT	5.2 ± 3.8**	2.5 ± 4.2*	0.06

AVOI, anatomical volume of interest; TP, temporal pole; ST, superior temporal; MT, middle temporal; R, right; L, left. Values are mean ± s.d.; **$p < 0.001$, *$p < 0.05$.

group functional lateralization index difference was generated by the right middle temporal activation observed in LH only; this reduced the leftward activation asymmetry in this group compared with RH, the left middle temporal activation amplitude being similar in both groups.

Taken together, the present results constitute, to our knowledge, the first evidence of a reduced functional asymmetry in the language areas of LH during speech auditory processing. They also demonstrate that during language comprehension, a temporal area, namely the right middle temporal gyrus, is recruited in LH while it is not or is indeed deactivated in RH. The middle temporal region has never been reported to be involved in previous language comprehension studies in RH.[12] Its activation in LH in the present study indicates that left-handers have an extended right hemisphere language representation, a finding in agreement with clinical studies that have shown frequent aphasia after right hemisphere posterior region lesions in LH.[24]

Correlation study between anatomical and functional lateralization: A significant positive correlation was observed between left PT surface and NrCBF activation both in the left superior temporal gyrus (r = 0.71, $p = 0.01$, Fig. 1) and in the temporal pole (r = 0.63, $p = 0.01$): subjects with larger left PT presented larger NrCBF increases in their left superior temporal gyrus and left temporal pole regions during speech listening. A significant positive correlation was also found between the left PT surface and the functional lateralization index in the temporal pole: subjects with larger left PT had a larger leftward dominance in the temporal pole during story listening (r = 0.68, $p = 0.007$). Interestingly, no correlation was found between the PT asymmetry index and functional data, a result similar to that of Jäncke.[11] Finally, no significant correlation was found between handedness scores and blood flow variations during story listening, mainly due to the important functional variability in LH. As a matter of fact, according to the aphasia literature, only 60% of LH present a leftward dominance.[24]

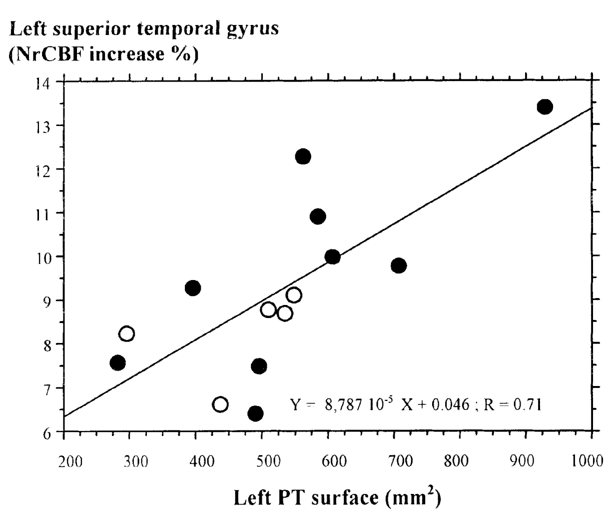

FIG. 1. Correlation between the left planum temporale surface with NrCBF increases in the superior temporal gyrus during the story listening task compared with a rest condition (14 subjects). Closed circles : right-handers, open circles: left-handers.

The observation of a positive correlation between left PT surface and left temporal cortex activation amplitude during language comprehension constitutes the major finding of the present study. It demonstrates that the variability in the size of a given structure of the temporal cortex explains, at least in part, the functional variability of the temporal cortex involvement during auditory language processing. As it stands, this result provides a strong argument in favor of Geschwind's hypothesis that PT anatomical leftward asymmetry reflects the left hemisphere functional dominance for language. One has to acknowledge, however, a limitation of the present study, namely the fact that NrCBF in PT itself could not be reliably measured because of the limited resolution of PET images. Therefore, it remains to be assessed whether larger increases of blood flow during speech listening in the left superior temporal region are due to larger NrCBF in PT itself. This could indeed be the case since the PT region can be confounded with the Tpt cytoarchitectonic area, a transitional cortex located at the interface between unimodal auditory cortex and integration cortex, lesions of which are known to generate language function disturbances.[25]

Two recent functional MRI studies have reported conflicting results regarding PT activation during language task. The first claimed that auditory word processing did not elicit more PT activation than tone sequences processing.[26] However, this finding could be explained, at least in part, both by image analysis limits (PT was defined after stereotactic averaging of the subject images and delineated on four 4 mm sagittal MRI slices, degrading the resolution to at least 15 mm[27]) and by the limited task complexity. A previous PET study found no difference in left superior temporal activations when comparing word and non-word processing, while the same region was more activated during verb generation.[28] Another FMRI study of sentence processing reported activations in superior temporal, including PT, that were increasing with sentence complexity.[29] This last result, consistent with that of the present report, underlines the difficulty in disentangling the specific PT contribution from that of the superior temporal gyrus during language processing, and points to the need for further high-resolution investigations to address this question. In addition, in the present study the left PT surface was found correlated not only with left superior temporal but also with left temporal pole activations and temporal pole functional asymmetry. The temporal pole region is structurally distinct from the left PT and its role in language processing seems to be related to story encoding linked with the processing of language-evoked emotions.[12,30] Therefore, the PT anatomical asymmetry, known to be settled as early as during the 32nd week of the fetal life,[31] may not be by itself the neural support of the functional lateralization for language but rather a witness of the early setting of dominance, which is eventually expressed in a network of language processing related regions. As a matter of fact, significant leftward asymmetries of activations during this story listening task were observed not only in superior temporal but also in the inferior frontal gyrus and in middle temporal cortex in RH subjects.[12]

Finally, a striking result is the absence of correlation with the right PT. This could indicate that right PT anatomical involution, that has been suggested to be at the origin of the developmental setting up of hemispheric dominance for language,[32] does not translate into a functional expression in adults.

Conclusion

The present results validate Geschwind's hypothesis that planum temporale anatomical asymmetry is linked to hemispheric dominance for language. They indicate that the size of the left PT is the relevant anatomical landmark for language dominance, and demonstrate that anatomical asymmetries are part of the functional variability for language.

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ACKNOWLEDGEMENTS: The authors are deeply indebted to the Service Hospitalier Frédéric Joliot (CEA-DSV, Orsay) radiochemistry staff for labeled water production, to Monique Crouzel and Laurence Laurier for data acquisition, to Emmanuel Mellet, Fabrice Crivello and Dimitri Papathanassiou for thoughtful discussions and to colleagues from the Laboratoire de Psycholinguistique (EHESS, Paris) for the tape recording of the stories.

Received 17 December 1997; accepted 15 January 1998