LANGUAGE LATERALIZATION EXPLAINED BY THE GENERALIZED FRACTIONAL ANISOTROPY IN THE AUDITORY NERVE AND THE CORPUS COLLOSUM AS STUDIED USING DIFFUSION SPECTRUM IMAGING TRACTOGRAPHY AND FMRI

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Introduction

We propose a new explanation for the mechanism of the language lateralization/asymmetry using the generalized fractional anisotropy (GFA) of diffusion spectrum imaging (DSI) as a measure of conductivity of neural fibers, specifically the auditory nerve (AN) and the corpus callosum (CC). The size of the CC was found to increase according to the degree of left language lateralization [1]. A large CC appears preferable for the faster transfer of the language information to the lateralized hemisphere. Which side is to be lateralized may be determined by properties in the hemisphere, such as the size and/or density of the neurons in Heschl's gyrus (HG) and/or the planum temporale (PT) [2]. One of the other candidates for the properties may be that of the AN. The leftward asymmetry of language was found in newborn babies specifically in the left PT, the auditory cortex [3], which strongly suggested hearing experiences during the uterus as the AN matures. We used the GFA derived from the orientation distribution function (ODF) as the measure of neural conductivity of the fiber tracts [4]. An fMRI was employed to determine the individual language asymmetry. People with ambilateral language function were hypothesized to have a lower GFA in the CC, specifically the part of which connects both sides of the HG, the primary auditory cortex. For people with higher GFA in the CC, the asymmetry might be explained by the GFA in the AN, although the nerves crossing in the auditory system should be noted. We assumed that the ipsilateral projection of the AN might affect the lateralization process more profoundly than the contralateral as considering the closer the more effective. The working hypothesis can be summarized as Table 1.

Materials and Methods

Twenty-two normal volunteers participated in this study (age 17-31, F/M = 9/13, right-/left-handed = 11/11, with written informed consent). All scanning was conduced on a 3 T MRI (Trio, Siemens, Erlangen, Germany). Volunteers performed a covert word generation for displayed category words during a block-design fMRI. The parameters were: TR/TE = 2000/45 ms, FA = 90 deg, FOV = 240 mm, 64*64 matrix, 3.8 mm thick with no gap, 34 slices per volume and 150 volumes per run. Activated voxels as analyzed using SPM5 were counted within Broca's and Wernicke's areas as well as the right homologues to compute a laterality index (LI(f), [Left – Right]/[Left + Right]). DSI was taken using the following parameters: TR/TE = 9100/142 ms, 128*128 matrix with an isotropic in-plane resolution of 2.9 mm by 2.9 mm, and 2.9 mm thickness each for 45 slices. A total of 203 diffusion-encoding gradients with maximum b-value 6000 s/mm2 were homogeneously sampled on a Cartesian lattice over 3D q-space. T2 anatomy images were also acquired. The tractography was conducted using inhouse software (DSI Studio, http://dsi-studio.labsolver.org/). Masks for the HG obtained from MARINA software was imported to the individual DSI space after the transformation from the MNI coordinates space using SPM coregistration and normalization parameters with T2 weighted images as the reference. The tracts for the AN were extracted from those that went through the masks of the HG and the medial geniculate nucleus. The tracts for the CC were extracted from those that went through the masks of the HG of both sides. The asymmetry of the AN was computed using the GFA of the AN (LI(an), [Left – Right]/[Left + Right]).

Results and Discussion

The AN was successfully extracted for all subjects, whereas the CC between both HGs could not be detected (N.D.) in 5 volunteers (Fig. 1). Our hypothesis appeared to be supported in general (Table 1). However, there were substantial individual variations in lateralization and the detection of CC. One reason for the variation might be that the lower conductivity in the CC would not necessarily preclude lateralization in the language function and in the AN. Actually, the classification of volunteers according to the GFA in the CC showed that people with higher GFA in the CC did not have bilateral language function (Fig. 2), partly supporting the hypothesis. Another reason for the variability of subjects might be the nerves crossing in the AN system. A classification by the LI(an) revealed that volunteers with left lateralized AN had all leftward asymmetry in fMRI, and that people with bilateral language function were all classified into mildly right lateralized AN. There was no "mildly left lateralized" people in this population. Interestingly, stronger right lateralization in the AN was also associated with the left language lateralization in fMRI, maybe because of the nerves crossing. Moreover, Welch two-sample t-test of the Left/Right vs. Mildly right lateralized AN showed that the GFA in the CC tended to be lower in the mildly lateralized AN people ($p<0.10$, $t=1.9023$, $df=14.723$, excluded N.D people, $N=17$). This lower conductivity in the CC might explain the bilateral language function in fMRI volunteers within this category (i.e. "Mildly right" in Fig. 3).

Conclusions

The GFA in the CC and the AN was found to explain the language lateralization at least partly. The left lateralized AN is thought to be most likely to be related to the leftward language asymmetry. The mild lateralization in the GFA of the AN as well as the lower GFA in the CC tend to be related with bilateral language function shown in fMRI.

Table 1. Relationship between language lateralization and GFA

Lateralization	Hypothesis		N	Results*	
	GFA in CC	GFA in AN		GFA in CC	LI in AN
Right: LI(f)<-0.20	High	Left < Right	3	0.326 (0.037)	-0.028 (0.008)
Bilateral: -0.20~0.20	Low	Left = Right	3	0.313 (0.001)	-0.017 (0.011)
Left: LI(f)>0.20	High	Left > Right	16	0.327 (0.022)	0.036 (0.075)

Notes. * Means (SD). Subjects whose CC could not be detected were excluded in GFA in CC.

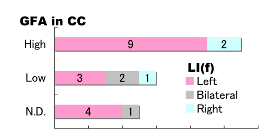

Fig. 2. Classification by GFA in CC. High, GFA>0.32; Low, GFA<0.32; N.D., not detected. Left, Bilateral and Right indicate the language lateralization by fMRI, LI(f). The numbers within the bars indicate subjects' number. N=22.

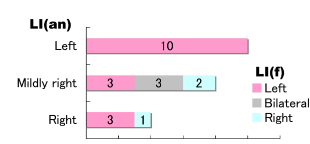

Fig. 3. Classification by GFA in AN. Left in the vertical axis, LI(an)>0.026; Mildly right, -0.026<LI(an)<0; Right, LI(an)<-0.026. The classification of the LI(f) is the same as in Fig. 2. The mean GFA in the CC was 0.327 for Left, 0.312 for Mildly right and 0.348 for Right (see text).

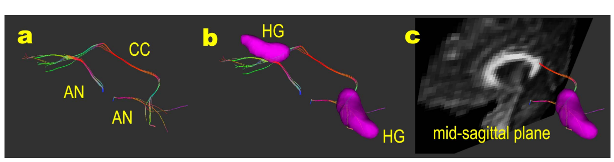

Fig. 1. Tractography of a representative subject. a: fibers only. b: masks of HG added. c: mid-sagittal plane added. The CC connecting HGs often crosses the upper splenium.

References

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