DTI tractography of theWernicke and Broca connectivity in right and left hander

P. Hagmann[1], L. Cammoun[1], R. Martuzzi[2], P. Maeder[2], S. Clarke[3], J-P. Thiran[1], R. Meuli[2]

[1]Signal Processing Institute, Swiss Federal Institute of Technology, Lausanne, Switzerland, [2]Department of Radiology, University Hospital, Lausanne, Switzerland, [3]Division of Neuropsychology, University Hospital, Lausanne, Switzerland

Introduction

In these last years fibre tracking has mainly focused on demonstrating its accuracy on single subject studies. The coming challenge is to answer neuro-anatomic questions by using the power of group studies. In that sense we illustrate with an example a general methodology to investigate the density of connection between two cortical locations among a chosen population of subjects. Left-right brain asymmetry in language areas has been greatly investigated in terms of cortical anatomy [1] and more recently by fMRI [2]. Never up to now, has this question been addressed in terms of DTI tractography. We use DT-MRI and statistical fibre tracking in order to quantify the left-right asymmetry of connectivity between the posterior part of the superior temporal gyrus (Wernicke) and the homolateral pars opercularis of the frontal inferior gyrus (Broca) in 12 healthy subjects.

Material and Methods

We investigated 7 Left Handed (LH) and 5 Right Handed (RH) healthy subjects as defined by the Oldfield test, at 1.5 T. We got from each volunteer 1) a single-shot EPI based DT-MRI dataset made of a 128x128x44 matrix with a voxel size of 1.64x1.64x3.00 mm3, TR/TE= 1000/89 ms and b-value=1000 s/mm2, 2) a high resolution MPRAGE and 3) a fMRI study (block design experiment) with a silent generation paradigm for the Broca area and a sentence recognition paradigm for the Wernicke area.

For RH, ROIs i.e. boxes, were centred on the fMRI activation corresponding to Wernicke and Broca areas. Identical ROIs were placed on the contro-lateral side according to symmetrical anatomic landmarks. For LH, the ROIs were centred on similar areas in the right and left hemisphere according fMRI activation present in both hemispheres (cyan boxes in Figures).

The underlying fibre tracking technique used is described in detail in [3]. Briefly, the fibres were grown by a random walk algorithm that propagates according to the local diffusive properties (local DT) under a regularity constraint. Such fibres were initiated randomly and uniformly all over the white matter thus generating a huge number of fibres (over 100’000) giving a statistical estimate of brain connectivity. Virtual dissection was performed by the previously defined ROIs.

For each subject this simulation was done twice, once on the real DT-MRI data and once on what we call a water brain. A subject’s water brain is its DT-MRI data where all the tensors in the white matter have been set isotropic with some noise added according to the SNR of the real acquisition. Fibre tracking in a water brain is only influenced by the brain geometry therefore guaranties that the bilateral placement of the ROIs is unbiased. In other words the ROIs placement as defined earlier show that in the water brain there are approximately as many fibres that connect the fronto-temporal areas as defined by the ROIs on the right than on the left hemisphere. The fibres that pass through ipsi-lateral frontal and temporal ROIs are selected on all subjects, on the right and the left hemisphere, on the real data and their respective water brains. The number of fibres (n) connecting these two ROIs are measured in each case. The count is then normalised in the following way:

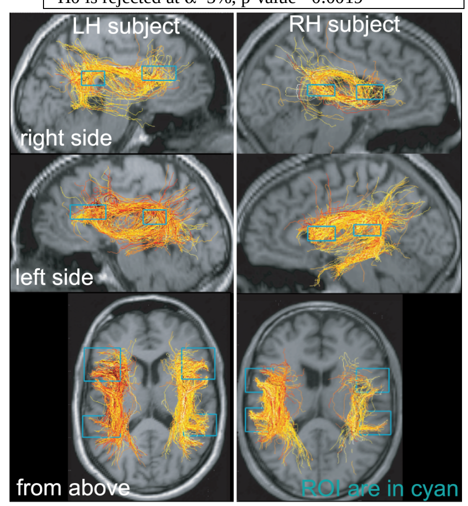
$N_{left} = n_{left} / (n_{left} + n_{right})$, $N_{right} = n_{right} / (n_{left} + n_{right})$. Table 1 summarises the data.

Table 1 :

mean ± SD	N_{left}	N_{right}
Right handed group, real DT-MRI	0.7237 ± 0.1527	0.2763 ±0.1527
Right handed group, water brain	0.4854 ±0.0389	0.5146 ±0.0389
Left handed group, real DT-MRI	0.3525 ±0.2056	0.6475 ±0.2056
Left handed group, water brain	0.5020 ±0.0230	0.4980 ±0.0230

Table 2 :

Exp.1: Lateralisation left of the RH population.
H0 $mean(NLRD^{RH}_{realDT}) \leq mean(NLRD^{RH}_{waterDT})$ H1 $mean(NLRD^{RH}_{realDT}) > mean(NLRD^{RH}_{waterDT})$
H0 is rejected at α=5%, p-value = 0.0098
Exp. 2: Lateralisation right of the LH population
H0 $mean(NLRD^{LH}_{realDT}) \geq mean(NLRD^{LH}_{waterDT})$ H1 $mean(NLRD^{Left}_{realDT}) < mean(NLRD^{Left}_{waterDT})$
H0 cannot be rejected at α=5%,, p-value=0.0522
Exp. 3: Lateralisation left of RH vs. LH population
H0 $mean(NLRD^{RH}_{realDT}) = mean(NLRD^{LH}_{realDT})$ H1 $mean(NLRD^{RH}_{realDT}) \neq mean(NLRD^{LH}_{realDT})$
H0 is rejected at α=5%, p-value =0.0019



Results

All the hypotheses are evaluated by Student testing on different values of NLRD, defined as the Normalized Left-Right Difference: $NLRD = N_{left} - N_{right}$. The H0 rejection level is α=5%.

Exp. 1: Lateralisation of the RH population. We determine whether there is a significant asymmetry in the connections between the superior temporal gyrus and the homo-lateral pars opercularis of the frontal inferior gyrus, i.e. significantly higher connectivity in the left hemisphere between those areas than in the right hemisphere. One can answer this question by comparing in the RH population the NLRD on the real DT-MRI vs. the NLRD of water brain (see Table 2 for H0 and H1 hypotheses). The unilateral student test allows us to reject H0, which means that the density of connection is significantly stronger left in the RH population (p-value = 0.0098).

Exp. 2: Lateralisation of the LH population. We want to know whether the LH population is lateralised to the right. Therefore we compare the NLRD of the real data with the data of the water brain (see Table 2). The hypothesis testing suggests that the LH population is less lateralised on the right at the limit of significance (p-value=0.0522).

Exp. 3: Lateralisation left of the RH vs. LH population. Comparing the real data of the RH vs. LH population, we investigate whether the language connectivity lateralisation is significantly different between LH and RH population. We conclude that there is a significant difference (p-value =0.0019).

Discussion

Our results show that the left-right brain asymmetry in the language area is not only limited to the cortex conformation, thickness and cytoarchitecture as known for a long time [1] but exists also in terms of connectivity. A RH population has association pathways between the superior temporal gyrus and the homo-lateral pars opercularis of the frontal inferior gyrus that are significantly stronger left (Broca-Wernicke) which seems to be fairly constant over that population (small variance). The LH population seems to be more heterogeneous in terms of lateralisation though if lateralized it will be frequently on the right. The language area association pathway has been classically described as being the arcuate fasciculus, some more recent concepts present an additional pathway mediated through the temporal lobe and the uncinate fasciculus [4]. In our data, most of the time Wernicke-Broca are connected by the arcuate fasciculus but in some cases we observed an additional temporal pathway potentially supporting the above concept.

Acknowledgments

This work was supported by the Swiss National Science Foundation grant number 3235B0-102868.

References

[1] Galaburda, et al. Science. 199:852-56,1978. [2] Fernandez G, et al. Neuroimage 14:585-94, 2001. [3] Hagmann P, et all. Neuroimage. 19:545-54, 2003. [4] Wise RJ. Br Med Bull. 65:95-119, 2003.