Effects of deafness and sign language fluency on white matter connectivity

Stephen McCullough and Karen Emmorey

Laboratory for Language & Cognitive Neuroscience, San Diego State University

Introduction

Both auditory deprivation and sign language exposure alter the gray and white matter structure of the human brain (Emmorey et al., 2003; Allen et al., 2013; Cheng et al., 2019; McCullough & Emmorey, 2021).

However, less is known about the pathway changes in white matter (WM) connectivity between brain areas in deaf signers, compared to hearing non-signers.

We investigated the effects of deafness and fluency in American Sign Language (ASL) on the white matter tractography using diffusion tensor imaging (DTI) and quantitative anisotropy (QA) based connectometry (Yeh, 2016).

Main research questions:

1. Which white matter tract changes are associated with deafness and/or sign language experience?

2. Which WM tract changes are correlated with sign language fluency?

Methods

Participants

Deaf native and early signers (n = 14, 8 females, mean age: 29.4 ± 4.3)
Hearing sign-naïve controls (n = 13, 8 females, mean age: 25.3 ± 5.8)

ASL Fluency

ASL skill was measured with the American Sign Language Sentence Reproduction Test (ASL-SRT) (Supalla et al., 2014). In this task, signers immediately repeat verbatim sentences of increasing complexity (N = 35). Mean ASL-SRT score = 25.6; range = 23 - 29.

Imaging methods

The preprocessing and analyses of structural and diffusion MRI data were carried out using AFNI (Cox, 1996) and DSI Studio (https://dsi-studio.labsolver.org)

Diffusion MRI data were acquired using 25 diffusion sampling directions with 2 mm in-plane resolution and 2 mm slice thickness then reconstructed in the MNI space using q-space diffeomorphic reconstruction to obtain the spin distribution function (Yeh et al., 2010; 2011).

A T-score threshold of 3.0 and tract length threshold of 20 mm were used in the deterministic fiber tracking algorithm (Yeh, 2016) to find tracts. To estimate the false discovery rate (FDR), 4000 randomized permutations were applied to the data to obtain the null distribution of the track length.

Statistical Analysis

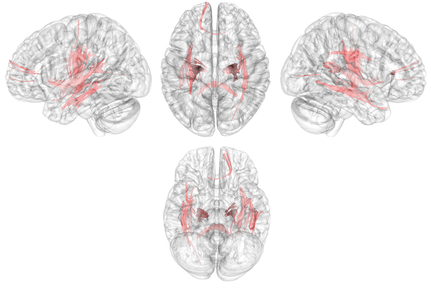
To examine the effect of deafness on WM connectivity, we performed a regression analysis, comparing deaf signers and hearing controls, on normalized quantitative anisotropy (QA) values with sex and age variables partialled out.

To determine the effect of ASL fluency on the WM connectivity in deaf signers, we conducted Pearson's correlation between normalized (QA) values with z-transformed ASL-SRT scores while partialling out the effects of age and sex.

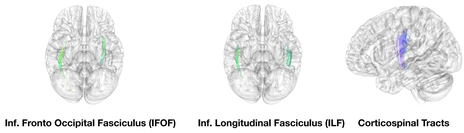
Results

Deaf vs. hearing sign-naïve control comparison

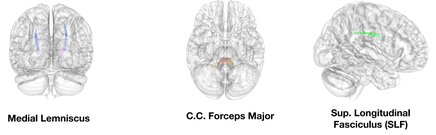
Group connectometry analysis results (thresholded at FDR ≤ .01) show increased QA for Deaf group only (red tracts). No tracts with negative QA were found.



Tracts showing Increased QA for deaf signers



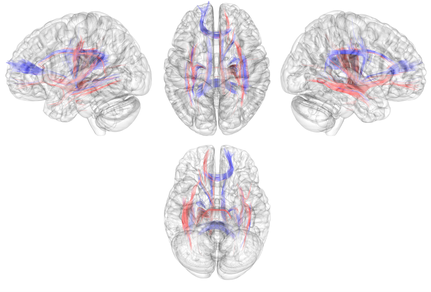
Inf. Fronto Occipital Fasciculus (IFOF) | Inf. Longitudinal Fasciculus (ILF) | Corticospinal Tracts



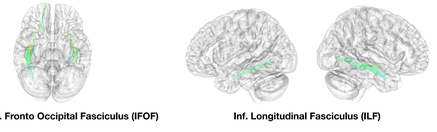
Medial Lemniscus | C.C. Forceps Major | Sup. Longitudinal Fasciculus (SLF)

Correlation with sign language fluency (Deaf only)

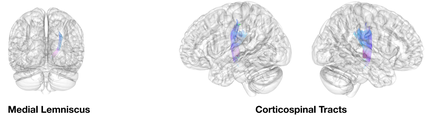
Correlational connectometry analysis results (thresholded at FDR ≤ .001) show positive correlation (red tracts) and negative correlation (purple tracts) between QA and Deaf signers' sign language Fluency.



Positive Correlation

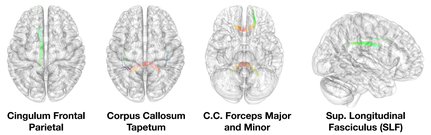


Inf. Fronto Occipital Fasciculus (IFOF) | Inf. Longitudinal Fasciculus (ILF)



Medial Lemniscus | Corticospinal Tracts

Negative Correlation



Cingulum Frontal Parietal | Corpus Callosum Tapetum | C.C. Forceps Major and Minor | Sup. Longitudinal Fasciculus (SLF)

Conclusions

Group connectometry contrast

The tracts associated with higher Quantitative Anisotropy (QA) values for deaf signers indicate more robust connections in visual, motor, somatosensory, and language pathways. The lack of decreased QA values for the auditory pathways is notable given previous studies showing white matter reduction for deaf individuals.

Distinct effects of auditory deprivation and sign language experience cannot be partialled out in this study. However, the known functions of the observed tracts provide some clues:

- The bilateral changes in the IFOF and IFL may arise from greater reliance on visual processing for deaf signers, due to auditory deprivation, integrating visual components during sign language processing, or both.
- The QA increases in the bilateral corticospinal tracts and medial lemniscus are more likely to arise from greater sensorimotoric processing demands of sign language production—e.g., coordinating arms and hands (Corticospinal Tracts) along with proprioceptive feedback and monitoring (Medial Lemniscus and right SLF).

Correlational connectometry

The tracts showing positive correlation between QA and ASL fluency provide other supporting evidence for relationship between sign language experience and the connection robustness in IFOF, IFL, Medial Lemniscus, and Corticospinal tracts.

The tracts showing negative QA correlations (i.e. Corpus Callosum Tapetum, Corpus Callosum Forceps Major and Minor) suggest that language regions in the left hemisphere of more fluent signers may be more efficient and thus, require less communication or engagement from the right hemisphere regions. The same principle may be true for the connections between the frontal and parietal cortices of more fluent signers.

References

Allen, J. S., Emmorey, K., Bruss, J., & Damasio, H. (2013). Neuroanatomical differences in visual, motor, and language cortices between congenitally deaf signers, hearing signers, and hearing non-signers. *Frontiers in Neuroanatomy*, *7*, 26.

Cheng, Q., Roth, A., Halgren, E., & Mayberry, R. I. (2019). Effects of Early Language Deprivation on Brain Connectivity: Language Pathways in Deaf Native and Late First-Language Learners of American Sign Language. Frontiers in Human Neuroscience, 13, 320.

Emmorey, K., Allen, J. S., Bruss, J., Schenker, N., & Damasio, H. (2003). A morphometric analysis of auditory brain regions in congenitally deaf adults. *Proceedings of the National Academy of Sciences of the United States of America*, *100*(17), 10049–10054.

McCullough, S., & Emmorey, K. (2021). Effects of deafness and sign language experience on the human brain: Voxel-based and surface-based morphometry. *Language, Cognition and Neuroscience*, *36*(4), 422–439.

Supalla, T., Hauser, P. C., & Bavelier, D. (2014). Reproducing American Sign Language sentences: Cognitive scaffolding in working memory. *Frontiers in Psychology*, *5*.

Yeh, F. C., Badre, D., & Verstynen, T. (2016). Connectometry: a statistical approach harnessing the analytical potential of the local connectome. *Neuroimage*, *125*, 162-171.

Acknowledgments

This research is supported by NIH Grant R01 DC010997 to San Diego State University and Karen Emmorey. Thank you to all who participated in our research.

Website https://llcn.sdsu.edu

Contact: stephen.mccullough@sdsu.edu