Impact of Age of Exposure to Sign Language and Cochlear Implantation on Spoken Language Outcomes

Background: The risks of language deprivation have been well-substantiated, and the neurobiological equivalence of signed and spoken languages has been established [1,2,3]. Nevertheless, controversy prevails surrounding the role of sign language exposure in the development of reading and spoken language skills for deaf people. On the one hand, it has been argued that conventional spoken language development relies heavily on early exposure to auditory and oral stimuli (*Maladaptive Auditory* Hypothesis) [4,5,6]. Conversely, other lines of research evidence (*Bilingual-Bimodal* Hypothesis) have suggested that early exposure to a natural signed language may offset the potential negative effects of language deprivation that some children experience and, at the least, do not harm global language outcomes [7,8,9].

Methods: In this novel functional near-infrared spectroscopy study (fNIRS), we examine the effects of American Sign Language (ASL) exposure at varying ages on deaf adult cochlear implant (CI) users' (N=32) English syntax processing. While undergoing fNIRS neuroimaging, participants performed a syntax judgment task. The task consisted of 80 sentences containing two types of relative clause structures with varying complexity: subject-object and object-subject. The sentences were further divided into conditions based on a plausibility distinction. Data was collected using a continuous-wave Hitachi ETG-4000 fNIRS neuroimaging system. Source-detector pairs were positioned using a three-dimensional digitizer and mapped to the cortical surface of an MNI-152 compatible canonical brain template [11,12].

Results: A whole-brain, channel-wise analysis (*Figures 1 & 2*) revealed that when making syntax judgments of relative clauses, participants were recruiting neural regions typically associated with semantics (e.g., the angular gyrus and the fusiform gyrus). We ran linear mixed-effects regression models on behavioral outcomes of interest (i.e., accuracy and reaction time), for which we found no statistically significant difference attributed to age of exposure to ASL (AoE). However, neural activation patterns differed as a function of AoE. A more focused analysis of activation uniquely predicted by AoE (*Figure 2*) revealed increased activation of primary-syntax regions (e.g., the left inferior frontal cortex and the left posterior superior temporal gyrus).

Discussion: Results from this study suggest that for adult bimodal-bilingual CI users, a combinatorial-semantic strategy may underlie syntax processing, at least for written English sentences. This work contributes to the mounting evidence that *early exposure to a signed language does not harm spoken language outcomes,* as results were in line with previously established performance metrics and that sign exposure may support cognitive strategies necessary for successful language and literacy acquisition. *After* conducting the initial analysis, we conducted an Analysis of Variance (ANOVA) to explore the effects of self-reported literacy skills on syntax judgments, where model predictions of accuracy significantly improved. This suggests that mere perception of literacy skills plays a significant role in syntactic plausibility judgment accuracy for deaf CI users. Further studies are needed to understand this effect better.

References: **1.** Hall, W. C., Levin, L. L., & Anderson, M. L. (2017). Language deprivation syndrome: A possible neurodevelopmental disorder with sociocultural origins. Social Psychiatry and Psychiatric Epidemiology, 52, 761-776. **2.** Krebs, J., Roehm, D., Wilbur, R. B., & Malaia, E. A. (2021). Age of sign language acquisition has lifelong effect on syntactic preferences in sign language users. International Journal of Behavioral Development, 45(5), 397-408. **3.** Petitto, L. A., Zatorre, R. J., Gauna, K., Nikelski, E. J., Dostie, D., & Evans, A. C. (2000). Speech-like cerebral activity in profoundly deaf people processing signed languages: implications for the neural basis of human language. Proceedings of the National Academy of Sciences, 97(25), 13961-13966. **4.** Kral, A., & Eggermont, J. J. (2007). What's to lose and what's to learn: development under auditory deprivation, cochlear implants and limits of cortical plasticity. Brain Research Reviews, 56(1), 259-269. **5.** Giraud, A. L., & Lee, H. J. (2007). Predicting cochlear implant outcome from brain organisation in the deaf. Restorative Neurology and Neuroscience, 25(3–4), 381–390. **6.** Campbell, J., & Sharma, A. (2016). Visual cross-modal re-organization in children with cochlear implants. PLoS One, 11(1), e0147793. **7.** Petitto, L. A., Langdon, C., Stone, A., Andriola, D., Kartheiser, G., & Cochran, C. (2016). Visual sign phonology: Insights into human reading and language from a natural soundless phonology. Wiley Interdisciplinary Reviews: Cognitive Science, 7(6), 366-381. **8.** Pontecorvo, E., Higgins, M., Mora, J., Lieberman, A. M., Pyers, J., & Caselli, N. K. (2023). Learning a sign language does not hinder acquisition of a spoken language. Journal of Speech, Language, and Hearing Research, 66(4), 1291-1308. **9.** Nematova, S., Zinszer, B. D., Morlet, T., Morini, G., Petitto, L., & Jasińska, K. K. (2023, April 7). Impact of ASL exposure on spoken phonemic discrimination in CI users. Advance Online Publication. https://doi.org/10.31234/osf.io/93eh4 **10.** Liu, F., Zhang, Z., Chen, Y., Wei, L., Xu, Y., Li, Z., & Zhu, C. (2023). MNI2CPC: A probabilistic cortex-to-scalp mapping for non-invasive brain stimulation targeting. Brain Stimulation, 16(6), 1733-1742. **11.** Singh, A. K., Okamoto, M., Dan, H., Jurcak, V., & Dan, I. (2005). Spatial registration of multichannel multi-subject fNIRS data to MNI space without MRI. NeuroImage, 27(4), 842-851.

Figure 1.: Significant neural activation of the Fusiform gyrus and the Angular gyrus. Here, cooler colors represent increased activation in the simple (OS) syntactic condition.

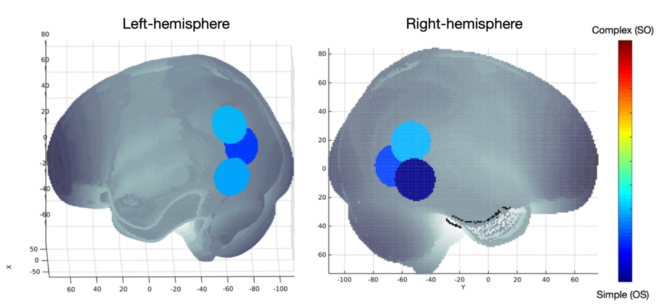

Figure 1.: Significant neural activation from region of interest analysis. Warmer colors represent increased activation in regions that can be explained by AoE alone.