Early-life signed language exposure does not impede the development of spoken language: A functional near infrared spectroscopy investigation of phonemic discrimination in cochlear implant (CI) users

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Controversy regarding the simultaneous use of signed and spoken language with cochlear implants (CI) persists

View 1
Early exposure to a signed language is detrimental to spoken language development through CI.

Geers et al., 2017
Peterson et al., 2010

View 2
Early signed language exposure does not harm language development, and may even offset the negative effects of language deprivation that children with CIs experience prior to implantation

Davidson et al., 2014
Jasinska et al., 2013
Petitto et al., 2016

To address this controversy, we examined neural activation patterns underlying phonemic discrimination (ability to distinguish phonemes) in individuals with CI who were both:
- exposed to signed language at different ages
- received their CI at different ages.

3 Hypotheses

H1. Only early exposure to a spoken language (via CI) supports phonemic discrimination. Early exposure to signed language has no impact (neither behavioral nor neural) on spoken language phonemic discrimination.

H2. Early exposure to a signed and a spoken language (i.e., simultaneous bimodal bilingualism) with early CI implantation, positively impacts spoken language phonemic discrimination.

H3. Early exposure to signed language has a negative impact on spoken language phonemic discrimination ability.

METHODS

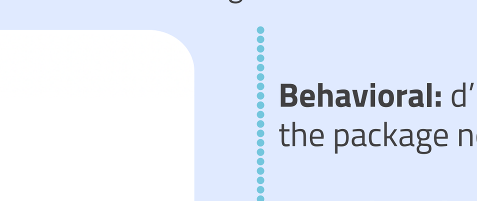
18 PARTICIPANTS
Mean Age = 19.9; SD=1.9
range=18-24 yrs

Recruited from Gallaudet University in Washington, D.C.

Language	Age of Exposure	Early (age = 0-5)	Late (age >5)
English (via CI)	M=8.5, SD=6.3, range=2-21 yrs	10	8
ASL	M=8.6, SD=7.6, range=0-22 yrs	10	8

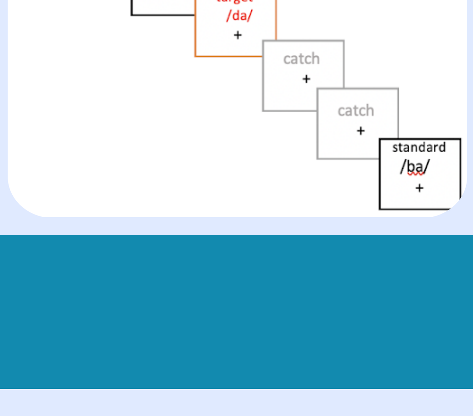
Participants completed an oddball paradigm phonemic discrimination (PD) task

Near Infrared Spectroscopy (fNIRS) neuroimaging: Hitachi ETG 4000



The task consisted of three phonetic categories:
(1) Native English phonetic units: /ba/-/da/
(2) Non-Native Hindi phonetic units: /ṱa/-/ʈa/
(3) Nonlinguistic pure tones

While undergoing fNIRS neuroimaging, participants performed an auditory target phoneme discrimination task using an oddball paradigm presented on a computer monitor using EPrime



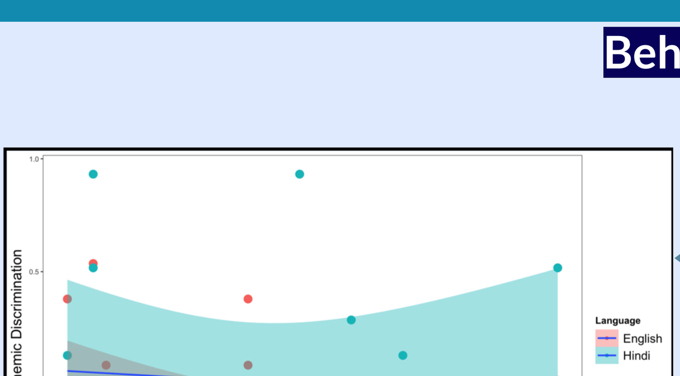
Behavioral: d' scores were calculated using the package neuropsychology v0.3.0 5 in R — Makowski, D. (2016)

Neuroimaging: Light intensities in fNIRS signals were analyzed using AnalyzIR toolbox; — Santosa et al. (2018)

Probabilistic probe registration were completed using NFRI functions — Singh et al. (2005)

RESULTS

Behavioral



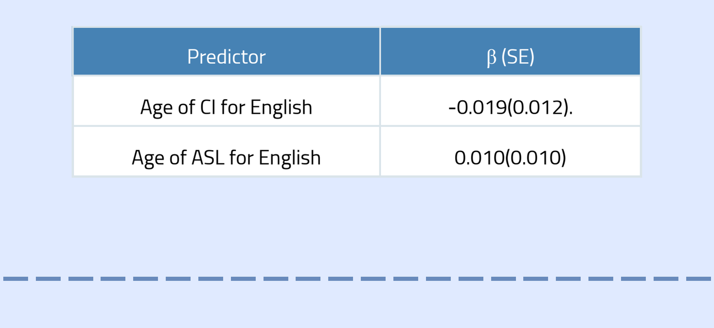
Age of CI x Language
Early CI implantation (but not Age of ASL) was associated with higher d' scores in English, but not in Hindi

Predictor	β (SE)
Age of CI for English	-0.019(0.012).
Age of ASL for English	0.010(0.010)

Age of CI x Age of ASL x Language
Early age of ASL had no negative impact on English PD for participants with early age of CI *(see Discussion)*

Predictor	β (SE)
Age of CI x Age of ASL x Language	-0.004(0.002).

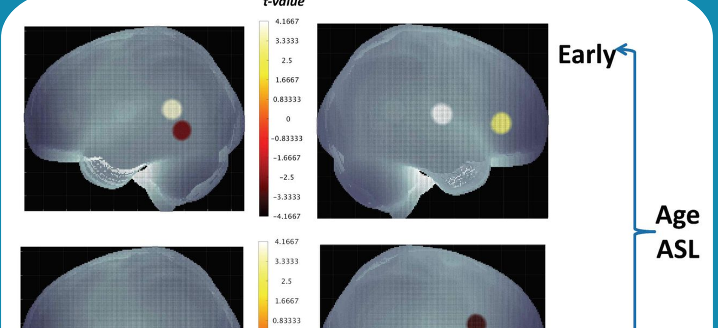
' 'p>.1; '.' p<.1; '*' p=.05; '**' p<.05; '***' p<.01; '****' p<.001



Neuroimaging

Age of ASL exposure
Early age of ASL: degree of activation increased in left hemisphere (LSTG) and right hemisphere (RSTG, RIPFG) language regions, but decreased in LMTG as the age of CI increased (Table 1A)

Late age of ASL: degree of activation decreased in pars triangularis in the right hemisphere as the age of CI increased (Table 1B)



Age of CI implantation
Early age of CI: degree of activation increased in right hemisphere language area (RSTG), but decreased in left hemisphere area (LMTG) as the age of CI increased (Table 2A)

Late age of CI: degree of activation decreased in right hemisphere language area (RMTG) and frontal eye fields as the age of CI increased (Table 2B)

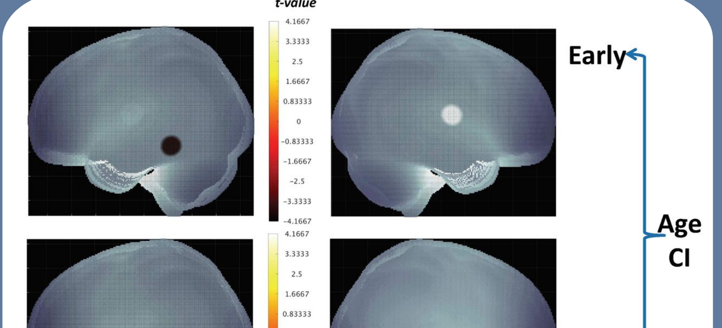


Table 1A

Early ASL (age =1)	β (SE) for Age CI
RSTG	4.025 (0.714)****
LSTG	2.794(0.615)****
RIPFG	2.236(0.642)***
LMTG	-4.152(1.245)***

Table 1B

Late ASL (age =16.21)	β (SE) for Age CI
R Broca's (pars triangularis)	-3.035 (0.727)****

Table 2A

Early CI (age =2.3)	β (SE) for Age ASL
RSTG	4.879 (0.648)****
LMTG	-5.346 (1.141)****

Table 2B

Late CI (age =14.6)	β (SE) for Age ASL
Frontal eye fields	-1.149 (0.489)***
RMTG	-1.253(0.356)***

' 'p>.1; '.' p<.1; '*' p=.05; '**' p<.05; '***' p<.01; '****' p<.001

CORRELATION BETWEEN NEUROMAGING AND BEHAVIORAL RESULTS

Condition	Brain Area	β (SE) for d' scores	q
Early Age-ASL, Early Age-CI	RSTG	3.136 (0.575)	<.05
	RMTG	1.771(0.446)	<.05
Early Age-ASL, Late Age-CI	R Frontal eye fields	2.371(0.585)	<.05
Late Age-ASL, Early Age-CI	RSTG	3.430(0.476)	<.01
	Wernicke's	-1.532(0.377)	<.05
	RMTG	1.719(0.442)	<.05
Late Age-ASL, Late Age-CI	R Frontal eye fields	2.281(0.579)	=.05

DISCUSSION

Behavioral

Early Age of CI was associated with better performance in the English PD task.

No negative impact of early simultaneous signed and spoken language exposure (via CI).

High degree of individual differences in PD ability; some CI users show poor PD despite early implantation.

Neuroimaging

Early language exposure (ASL and/or via CI) is associated with greater activation of LH language areas that are critically involved in auditory phoneme detection and their right hemisphere homologues. However, we also observed some reduced LMTG activation for early CI and early ASL exposure.

Late language exposure (ASL and/or via CI) is associated with greater RH activation. Corroborates previous findings with new bimodal English (via CI)-ASL bilinguals: Later age of language exposure is associated with poorer language proficiency and greater RH activation (Hull & Vaid, 2006).

Brain-Behavior Correlation

Early language exposure (ASL and/or via CI)
There was a positive relationship between early language exposed individuals' ability to discriminate phonemes and degree of neural activation in the right-hemisphere language network.

Late language exposure (ASL and/or via CI)
This relationship was not found for individuals with late language exposure (ASL and/or CI)

This could be due to, at least in part, the presence of cognitive demand in phonemic discrimination task.

Activation in right-hemisphere language areas were found to be related to the recruitment of additional executive processes such as selective attention and/or manipulation in working memory of verbal material. Petit et al.(2007); Vigneau et al. (2011)

Distinguishing phonetic contrast [b] and [d] might have increased attentional demands by requiring participants to attend selectively to the first phoneme.

Supports Hypothesis 1

Exposure to signed language early in life has no negative impact on spoken language phonemic discrimination ability

2 sets of sources that might explain the variability in the results:
ASL: Quality and quantity of early ASL input, source of language input (i.e. from a non-proficient ASL user)

CI: Status of auditory nerves before implantation, lack of language therapy, limited benefits from CI and/or irregular use

FUTURE DIRECTIONS

Why do some individuals show poor phonemic discrimination and decreased left hemisphere neural activity despite receiving their implants early?

(1) Investigate additional sources of variation in CI users' PD abilities: status of auditory nerves and quantity and quality of language input after implantation

(2) Investigate neurobiological basis of PD in young CI users during sensitive periods for language acquisition immediately post implantation and examine changes in neural pathways underlying PD over time.

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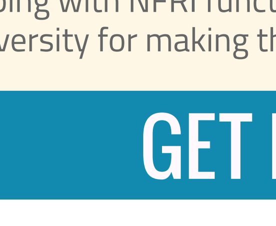
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REFERENCES

Davidson, K., Lillo-Martin, D., & Chen Pichler, D. (2014). Spoken english language development among native signing children with cochlear implants. The Journal of Deaf Studies and Deaf Education, 19(2), 238-250.

Geers, A. E., Mitchell, C. M., Warner-Czyz, A., Wang, N., Eisenberg, L. S., & CDaCI Investigative Team. (2017). Early sign language exposure and cochlear implantation benefits. Pediatrics, 140(1), e20163489.

Hull, R., & Vaid, J. (2006). Laterality and language experience. Laterality, 11(5), 436-464.

Jasinska, K., Langdon, C., & Petitto, L. A. (2013). Does early exposure to a visual signed language "hurt" auditory language tissue development: Evidence from fNIRS neuroimaging of language processing in deaf individuals cochlear implants. Society for Neuroscience, San Diego, CA.

Makowski, D. (2016). Package 'neuropsychology': An R Toolbox for Psychologists, Neuropsychologists and Neuroscientists. Available from https://github.com/neuropsychology/neuropsychology.R

Peterson, N. R., Pisoni, D. B., & Miyamoto, R. T. (2010). Cochlear implants and spoken language processing abilities: Review and assessment of the literature. Restorative Neurology and Neuroscience, 28(2), 237-250.

Petit, L., Simon, G., Joliot, M., Andersson, F., Bertin, T., Zago, L., ... & Tzourio-Mazoyer, N. (2007). Right hemisphere dominance for auditory attention and its modulation by eye position: an event related fMRI study. Restorative neurology and neuroscience, 25(3-4), 211-225.

Petitto, L., 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.

Santosa, H., Zhai, X., Fishburn, F., & Huppert, T. (2018). The NIRS brain AnalyzIR toolbox. Algorithms, 11(5), 73.

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.

Vigneau, M., Beaucousin, V., Hervé, P. Y., Jobard, G., Petit, L., Crivello, F., ... & Tzourio-Mazoyer, N. (2011). What is right-hemisphere contribution to phonological, lexico-semantic, and sentence processing?: Insights from a meta-analysis. Neuroimage, 54(1), 577-593.

Abbreviations
LH - left hemisphere
RH - right hemisphere
LSTG - left superior temporal gyrus
LMTG - left middle temporal gyrus
RSTG - right superior temporal gyrus
RMTG - right middle temporal gyrus
RIPFG - right inferior prefrontal gyrus