Spatial Auditory Attention with Magnified Interaural Level Difference Cues

Benjamin N. Richardson[1], Jana M. Kainerstorfer[1,2], Barbara G. Shinn-Cunningham[1,2], Christopher A. Brown[3]

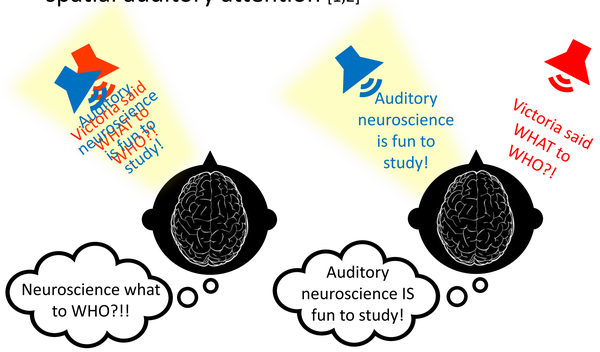
[1]Neuroscience Institute, Carnegie Mellon University; [2]Biomedical Engineering, Carnegie Mellon University;
[3]Communication Science and Disorders, University of Pittsburgh

HYPOTHESES

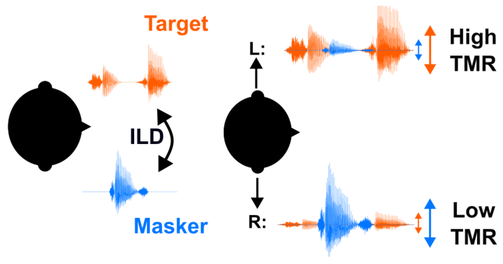
1. Larger spatial cues will lead to better performance on a spatial auditory attention task
   - Large ITDs > Small ITDs
   - Broadband ILDs > Naturally occurring ILDs
2. Larger spatial cues will reduce cognitive effort
   - Reduced activation in prefrontal cortex (PFC)
   - No change in superior temporal gyrus (STG)

BACKGROUND

- Spatial release from masking (SRM) relies on spatial auditory attention [1,2]



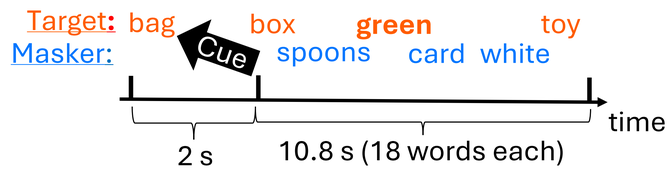
- Interaural time differences (ITDs) and interaural level differences (ILDs) support SRM by allowing:
  - Segregation of sound sources [3,4,5]
  - Focus of spatial attention [1,6]
- Naturally occurring ILDs improve acoustic target-to-masker ratio (TMR) at the ear closer to the target [7,8], whereas ITDs do not



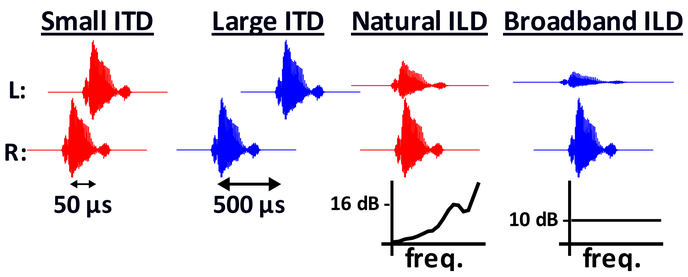
BEHAVIOR

MATERIALS & METHODS

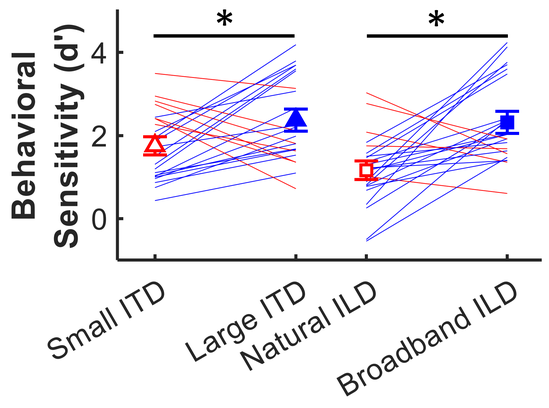
- N = 23 normal hearing subjects
- Target was to the left or right, Masker on the other side
- Subjects responded to **color words** in the target stream
- Subjects ignored the masker stream
- Target and masker word pairs were jittered in time
- 16 trials per condition (8 attend left, 8 attend right)



Spatial Conditions



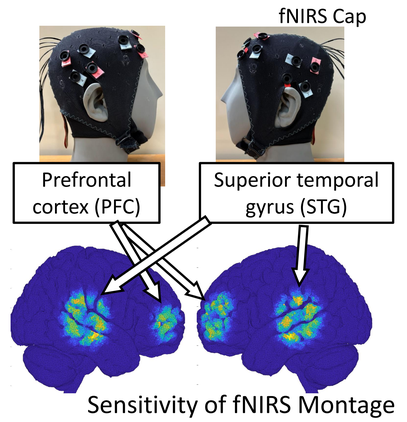
RESULTS: Larger spatial cues lead to better performance



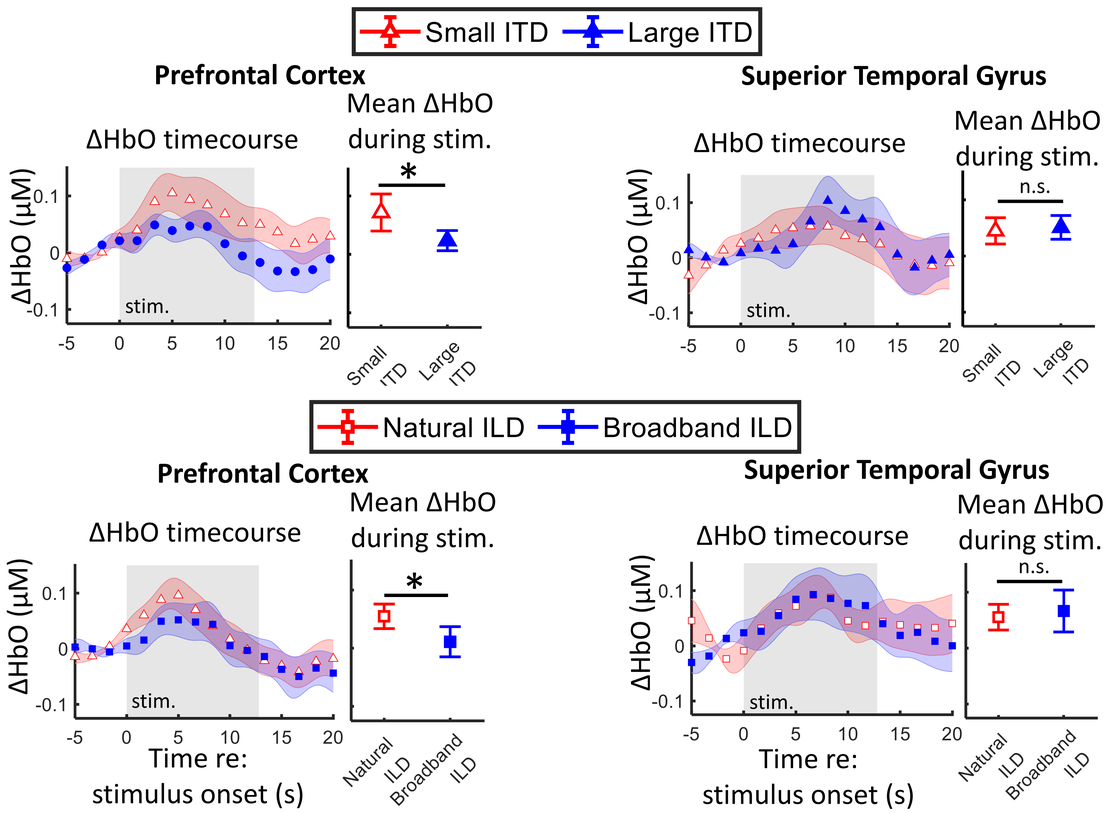
NEUROIMAGING

MATERIALS & METHODS

- We recorded hemodynamic responses using functional near-infrared spectroscopy (fNIRS) on the same task
- Optical intensity was converted to change in oxygenated (ΔHbO) and deoxygenated (ΔHbR) hemoglobin concentration
  - Bandpass filtered (0.01-0.3 Hz), motion artifacts removed
  - Epoched, baselined to average of 5 sec prior to sound onset
  - Noisy epochs rejected based on peak-to-peak amplitude
  - Averaged across channel and trial



RESULTS: Larger spatial cues lead to reduced PFC activity, without changing STG activity



REFERENCES

1. Noyce AL, Kwasa JAC, Shinn-Cunningham BG. Defining attention from an auditory perspective. WIREs Cognitive Science. 2021;n/a(n/a):e1610. doi:10.1002/wcs.1610
2. Litovsky RY. Spatial Release from Masking. Acou Today. 2012;8(2):18. doi:10.1121/1.4729575
3. Best V, Ozmeral E, Gallun FJ, Sen K, Shinn-Cunningham BG. Spatial unmasking of birdsong in human listeners: Energetic and informational factors. The Journal of the Acoustical Society of America. 2005;118(6):3766-3773. doi:10.1121/1.2130949
4. Ihlefeld A, Shinn-Cunningham B. Spatial release from energetic and informational masking in a selective speech identification taska). The Journal of the Acoustical Society of America. 2008;123(6):4369-4379. doi:10.1121/1.2904826
5. Middlebrooks JC, Waters MF. Spatial Mechanisms for Segregation of Competing Sounds, and a Breakdown in Spatial Hearing. Front Neurosci. 2020;14:571095. doi:10.3389/fnins.2020.571095
6. Shinn-Cunningham BG, Best V. Selective attention in normal and impaired hearing. Trends Amplif. 2008;12(4):283-299. doi:10.1177/1084713808325306
7. Glyde H, Buchholz J, Dillon H, Best V, Hickson L, Cameron S. The effect of better-ear glimpsing on spatial release from masking. The Journal of the Acoustical Society of America. 2013;134(4):2937-2945. doi:10.1121/1.4817930
8. Glyde H, Buchholz JM, Dillon H, Cameron S, Hickson L. The importance of interaural time differences and level differences in spatial release from masking. The Journal of the Acoustical Society of America. 2013;134(2):EL147-EL152. doi:10.1121/1.4812441
9. Zhou X, Burg E, Kan A, Litovsky RY. Investigating effortful speech perception using fNIRS and pupillometry measures. Current Research in Neurobiology. 2022;3:100052. doi:10.1016/j.crneur.2022.100052
10. White BE, Langdon C. The cortical organization of listening effort: New insight from functional near-infrared spectroscopy. NeuroImage. 2021;240:118324. doi:10.1016/j.neuroimage.2021.118324
11. Defenderfer J, Forbes S, Wijeakumar S, Hedrick M, Plyler P, Buss AT. Frontotemporal activation differs between perception of simulated cochlear implant speech and speech in background noise: An image-based fNIRS study. NeuroImage. 2021;240:118385. doi:10.1016/j.neuroimage.2021.118385
12. Wijayasiri P, Hartley DEH, Wiggins IM. Brain activity underlying the recovery of meaning from degraded speech: A functional near-infrared spectroscopy (fNIRS) study. Hearing Research. 2017;351:55-67. doi:10.1016/j.heares.2017.05.010
13. Luke R, Larson ED, Shader MJ, et al. Analysis methods for measuring passive auditory fNIRS responses generated by a block-design paradigm. NPh. 2021;8(2):025008. doi:10.1117/1.NPh.8.2.025008
14. Mushtaq F, Wiggins IM, Kitterick PT, Anderson CA, Hartley DEH. Investigating Cortical Responses to Noise-Vocoded Speech in Children with Normal Hearing Using Functional Near-Infrared Spectroscopy (fNIRS). JARO. 2021;22(6):703-717. doi:10.1007/s10162-021-00817-z
15. Zhang M, Alamatsaz N, Ihlefeld A. Hemodynamic Responses Link Individual Differences in Informational Masking to the Vicinity of Superior Temporal Gyrus. Front Neurosci. 2021;15:675326. doi:10.3389/fnins.2021.675326
16. Middlebrooks JC, Waters MF. Spatial Mechanisms for Segregation of Competing Sounds, and a Breakdown in Spatial Hearing. Front Neurosci. 2020;14:571095. doi:10.3389/fnins.2020.571095
17. Higgins NC, McLaughlin SA, Rinne T, Stecker GC. Evidence for cue-independent spatial representation in the human auditory cortex during active listening. Proceedings of the National Academy of Sciences. 2017;114(36):E7602-E7611. doi:10.1073/pnas.1707522114
18. Bonacci LM, Bressler S, Shinn-Cunningham BG. Nonspatial Features Reduce the Reliance on Sustained Spatial Auditory Attention. Ear Hear. 2020;41(6):1635-1647. doi:10.1097/AUD.0000000000000879
19. Brown CA. Binaural Enhancement for Bilateral Cochlear Implant Users. Ear Hear. 2014;35(5):580-584. doi:10.1097/AUD.0000000000000044Brown 2018
20. Richardson, B.N., Kainerstorfer, J.M., Shinn-Cunningham, B.G., Brown, C.A. Magnified Interaural Level Differences Enhance Spatial Release from Masking in Bilateral Cochlear Implant Listeners (in review).

DISCUSSION

- Large ITDs and ILDs increase perceptual lateralization of sound sources, leading to greater SRM and reduced cognitive effort.
- Hemodynamic activity in PFC increased with task difficulty, but responses in STG did not.
  - Activity in PFC reflects listening effort and task difficulty [9,10,11].
  - Responses in STG largely reflect spectrotemporal content [11,12,13,14,15], independent of perceived location [16,17,18]
- Magnified ILDs may improve SRM in hearing impaired listeners, especially cochlear implant users, who have limited access to ITDs [19,20].

FUNDING

R21-DC018408 to CAB
R01-DC015988 to BGSC
NIH NIDCD

https://apc.casa/posters/