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Leveraging adaptation to study perceptual weighting of interaural time differences

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Abstract

An important question in auditory cognition is how we perceive the location of an object in space. Converging evidence from animal models and humans suggests that when judging sound direction, the central nervous system weighs the anticipated reliability of binaural cues. Here, we used short-term adaptation to bias normal-hearing listeners towards source direction favoring either the left or the right frontal quadrant. Listeners rated perceived laterality of tokens of band-pass filtered noise (300 Hz – 1200 Hz) with interaural time differences that were randomly selected from a uniform distribution spanning either -375 to 0 μs or 0 to 375 μs. Using non-linear mixed effects modeling of behavioral laterality reports, we tested how exposure to source quadrant affects how listeners weigh the reliability of interaural time differences. The cue reliability hypothesis predicts that perceived direction should be skewed, such that unreliable frontal source angles are more affected by short-term adaptation than the more reliable lateral source angles. Alternatively, short-term adaptation may affect all source angles equally, predicting an overall shift in perceived direction. Results show that frontal angles are more strongly affected by short-term adaptation than lateral angles, supporting the cue reliability hypothesis.

Keywords: functional near infrared spectroscopy, cochlear implant

1 INTRODUCTION

A wide range of species relies on sound localization for both navigation and auditory scene analysis. For low-frequency sound, interaural time differences (ITDs) are the dominant cue for determining the direction of a source in the horizontal plane, a phenomenon called sound lateralization. The mechanisms by which the nervous system maps ITD into perceived sound direction are incompletely understood.

In anechoic spaces, a given source angle in the horizontal plane typically gives rise to the same ITD, across a wide range of source distances. However, in everyday environments where background sound and reverberant energy are often present, ITDs are much less reliable indicators of source direction. This raises the possibility that when estimating source direction, a listener's interpretation of ITD changes depending on the context of the listening environment. Indeed, previous work shows plasticity in perceived sound direction across a wide range of conditions, including: 1) Prolonged exposure to constant interaural delays (Javer and Shwarz, 1995), 2) Modifications to shape of the pinnae (Hofman et al., 1998), 3) Long-term procedural learning (Wright and Fitzgerald, 2001), 4) Chronic unilateral ear plugging (Kumpik et al., 2010), 5) Short-term adaptation to stimulus history (Stange et al., 2013), 6) In presence of preceding distractors (Kopčo et al., 2017).

However, we have an incomplete understanding of short-term adaptation of sound lateralization based on the overall uncertainty of ITDs. The steepest point of the psychometric function linking ITD and perceived laterality is midline (the frontal direction). Thus, a small change in ITD around 0μs baseline ITD causes a much larger change in perceived laterality than a small change in ITD around 375μs ITD. Thus, the cue reliability hypothesis predicts that perceived direction should be skewed, such that unreliable frontal source angles are more affected by short-term adaptation than the more reliable lateral source angles. Alternatively, short-term adaptation may affect all source angles equally, predicting an overall shift in perceived direction. Leveraging short-term plasticity based on stimulus context, we set out to test the cue reliability hypothesis in human psychophysics experiments. We varied context by blocking stimuli such that they would predominantly arise

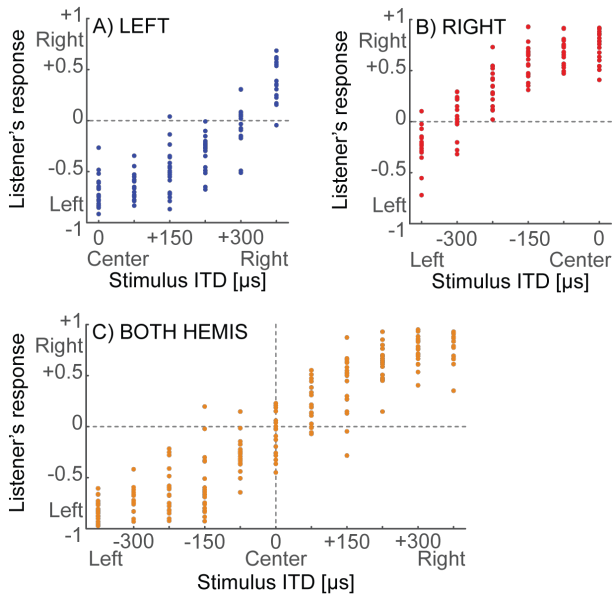

Figure 1. Raw lateralization scores from one representative listener.

from the left, from the right or from both sides of the head. Normal-hearing listeners judged lateralization of band-limited noise tokens as a function of interaural time difference and context.

2 METHODS

Overall methods were similar to previous work (for detailed description see: Ihlefeld et al. 2018). We tested 34 naïve normal-hearing listeners, 16 females, age 20-30. Audiometric thresholds were 20 dB HL or better at all octave frequencies and did not differ by more than 10 dB across ears at each octave frequency. We divided our listeners into four groups. Using a target matching task without response feedback, we initially trained three groups to be reliable reporters. Listeners trained and tested on the frontal 1) left hemisphere (LEFT HEMI, N=8) or, 2) right hemisphere (RIGHT HEMI, N=8)or, 3) both hemispheres (BOTH HEMIS, N=10). A fourth control group, NAÏVE RIGHT HEMI (N=8) was tested on the right frontal hemisphere without training.

Listeners were seated in a double-walled sound-attenuating booth. Sounds were presented through ER-2 earphones. Stimulus consisted of a band-limited random noise token, generated independently on each trial (300 to 1200 Hz, 1 sec duration, 10 ms cos-squared onset/offset ramps, 192 kHz sampling frequency, 24 bit resolution, 0 dB ILD). ITDs covered the range of 0, ± 75, ± 150, ± 225, ± 300 or ± 375 μs. Sound levels varied from 10 to 40 dB sensation level (SL).

Prior to testing all sounds were calibrated using KEMAR manikin and BK 2250 with 2-cc coupler. This study was approved by the NJIT Institutional Review Board.

All listeners performed three training sessions (except the naive group) and then a single session of testing. Each group were presented with their associated range of ITDs, i.e. RIGHT HEMI: positive ITDs only (including 0), LEFT HEMI: negative ITDs only (including 0), BOTH HEMI: full range of ITDs.

2.1 Results

Figure 1 shows the results of a representative listener. Results follow the expected sigmoidal trend. Thus, a non-linear mixed-effects model (NLME) capturing sigmoidal sensitivity was developed to analyze the data (for details, see Ihlefeld et al. 2018).

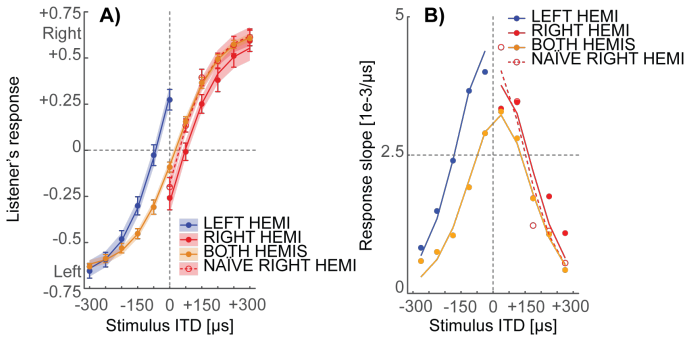

Figure 2. Fitted lateralization curves across all four context groups.

Figure 2A shows the responses of all 34 participants in the lateralization task. Circles show the raw across-listener average for each corresponding ITD and listener group, with error bars showing one standard error of the mean across listeners. Lines are the fitted model value, with ribbons indicating the predicted standard error of the mean fit. Figure 2B shows the slopes of these fits as a function of ITD.

2.2 Discussion

At the least reliable cue point, 0μs, results show robust response biases in all unilaterally tested listeners towards the opposite side, with a larger effect for the trained group versus the naïve. In contrast, lateralization at 375μs base ITD is not appreciably affected by context. Moreover, slope of lateralization curves increases for unilateral groups compared to the bilateral, hinting at an expansion in the perceived space and increase in lateralization sensitivity. Thus, despite the fact that humans are much more sensitive to frontal ITD than lateral ITD, as evidenced by lower just-noticable differences in ITD discrimination (Brughera and Hartmann, 2013), frontal ITDs are also more susceptible to short-term adaptation than lateral ITDs, supporting the cue reliability hypothesis.

3 CONCLUSIONS

Current results support the idea that short-term plasticity of ITD is more pronounced in front than at the sides.

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REFERENCES

[1] Javer, A.R.; Schwarz, D.W. Plasticity in human directional hearing. The Journal of otolaryngology. 1995 Apr;24(2):111-7.

[2] Hofman PM, Van Riswick JG, Van Opstal AJ. Relearning sound localization with new ears. Nature neuroscience. 1998 Sep;1(5):417.

[3] Wright BA, Fitzgerald MB. Different patterns of human discrimination learning for two interaural cues to sound-source location. Proceedings of the National Academy of Sciences. 2001 Oct 9;98(21):12307-12.

[4] Kumpik DP, Kacelnik O, King AJ. Adaptive reweighting of auditory localization cues in response to chronic unilateral earplugging in humans. Journal of Neuroscience. 2010 Apr 7;30(14):4883-94.

[5] Kopčo N, Andrejková G, Best V, Shinn-Cunningham B. Streaming and sound localization with a preceding distractor. The Journal of the Acoustical Society of America. 2017 Apr;141(4):EL331-7.

[6] Stange A, Myoga MH, Lingner A, Ford MC, Alexandrova O, Felmy F, Pecka M, Siveke I, Grothe B. Adaptation in sound localization: from GABA B receptor–mediated synaptic modulation to perception. Nature neuroscience. 2013 Dec;16(12):1840.

[7] Pinheiro, J.Bates; D. DebRoy, S.;Sarkar, D. and R Core Team, "nlme: Linear and Nonlinear Mixed Effects Models." 2018.

[8] Ihlefeld, A., Alamatsaz, N. and Shapley, R.M., 2018. Human Sound Localization Depends on Sound Intensity: Implications for Sensory Coding. bioRxiv, p.378505.

[9] Brughera, A.; Dunai, L. ; Hartmann, W.M., 2013. Human interaural time difference thresholds for sine tones: The high-frequency limit. The Journal of the Acoustical Society of America, 133(5), pp.2839-2855.