Discrimination of spectrotemporal ripple sweep direction near detection threshold

Christopher Conroy, Andrew J. Byrne, and Gerald Kidd, Jr.
Department of Speech, Language & Hearing Sciences and Hearing Research Center, Boston University

Background

Human listeners can discriminate between spectrotemporal ripples sweeping in one direction versus the other. Single neurons in the auditory systems of some animals also exhibit differentiated responses [e.g., Depireux et al., J. Neurophysiol. **85**, 1220-1234 (2001)]. It has been suggested that the perception of ripples by humans may be mediated by similar, ripple-tuned neurons, i.e., that there are neurons in the human auditory system that act as "labeled lines" [cf. Rose, Percept. **28**, 675-685 (1999)] by which human listeners perceive ripples. In this study, we sought behavioral evidence consistent with this proposition, and, in particular, with the possibility that the labeled-line-type mechanisms are tuned to ripple sweep direction.

Approach

As an approach, we used the "2x2 forced-choice" simultaneous detection and discrimination paradigm was employed [Nachmias and Weber, Vision Res. **15**, 217-223 (1975)]. This psychophysical paradigm has been used extensively to test for labeled-line-type mechanisms in the human visual system [see, e.g., Thomas, J. Opt. Soc. Am. A, **2** 1457-1467 (1985) for a review]. On each trial of our version of the task (see **Task**), the listener heard two brief sounds presented in two separate observation intervals: an unmodulated noise (reference or blank) and a noise modulated by either an upward sweeping or downward sweeping ripple. The listener then registered two separate responses: a detection response (Was the ripple in the first or second interval?) and a discrimination response (Was it sweeping upward or downward?). Labeled-line theory predicts that a correct detection response should always yield a correct discrimination response. Any deviation from this prediction, therefore, suggests either no labeled lines (defined as independent sensory channels) or, adopting a less stringent definition of labeled lines, overlap of the channels' sensitivities.

Methods

Observers: Seven young adults with normal hearing.
Carrier: 100, equal-amplitude, random-phase tones, log-spaced from 0.25 to 4.0 kHz. 500-ms total duration.
Ripples: +/-8 Hz / 1 cycle/octave
Procedures: Psychometric functions relating the proportion of correct detection or discrimination responses to ripple modulation depth were sampled using the method of constant stimuli. Feedback was provided on all trials (both responses).

Task

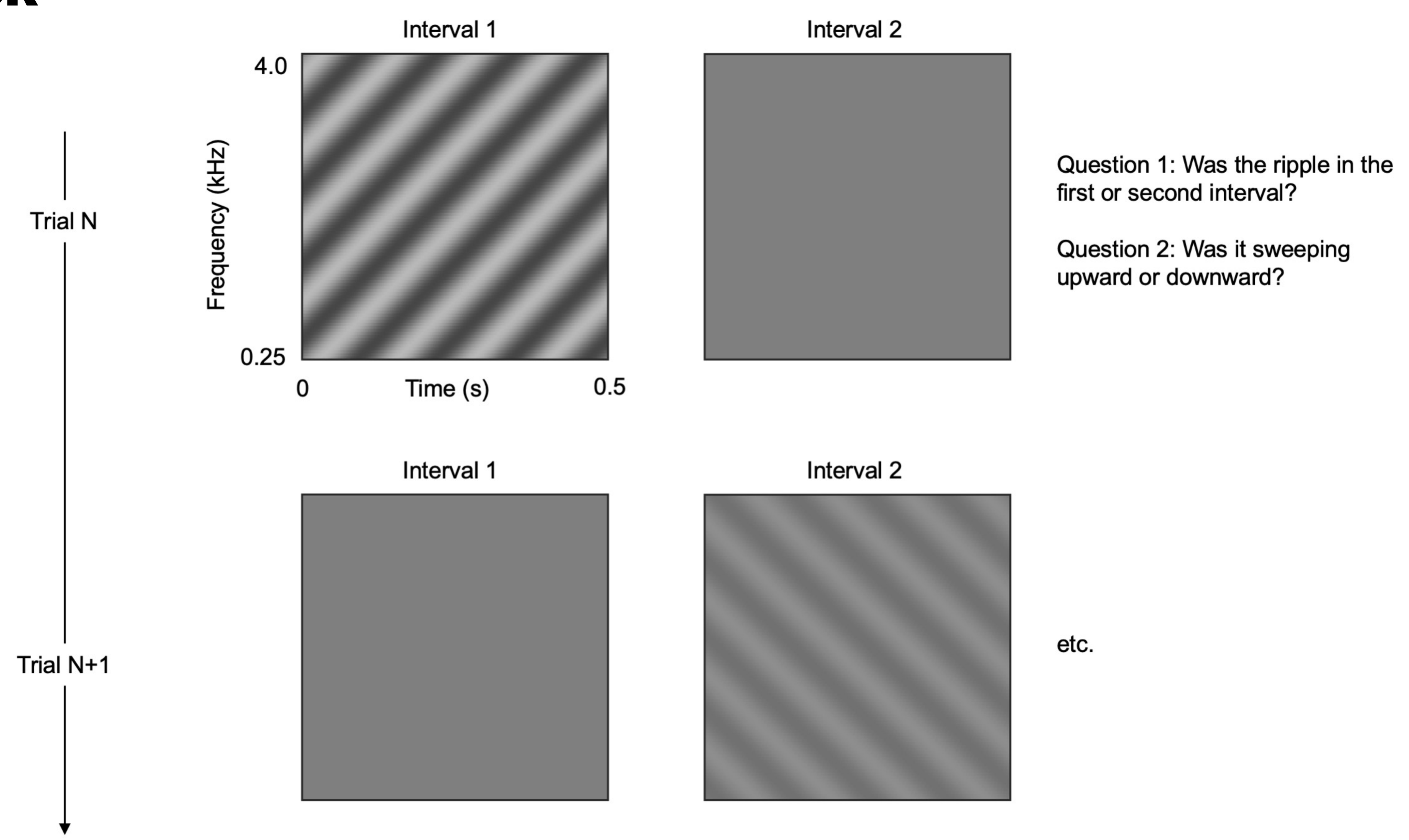

Fig. 1: Schematic of the stimuli and task. Each square shows the spectrogram of a stimulus envelope. Grayscale values indicate envelope amplitude, with darker values indicating greater amplitude.

Results

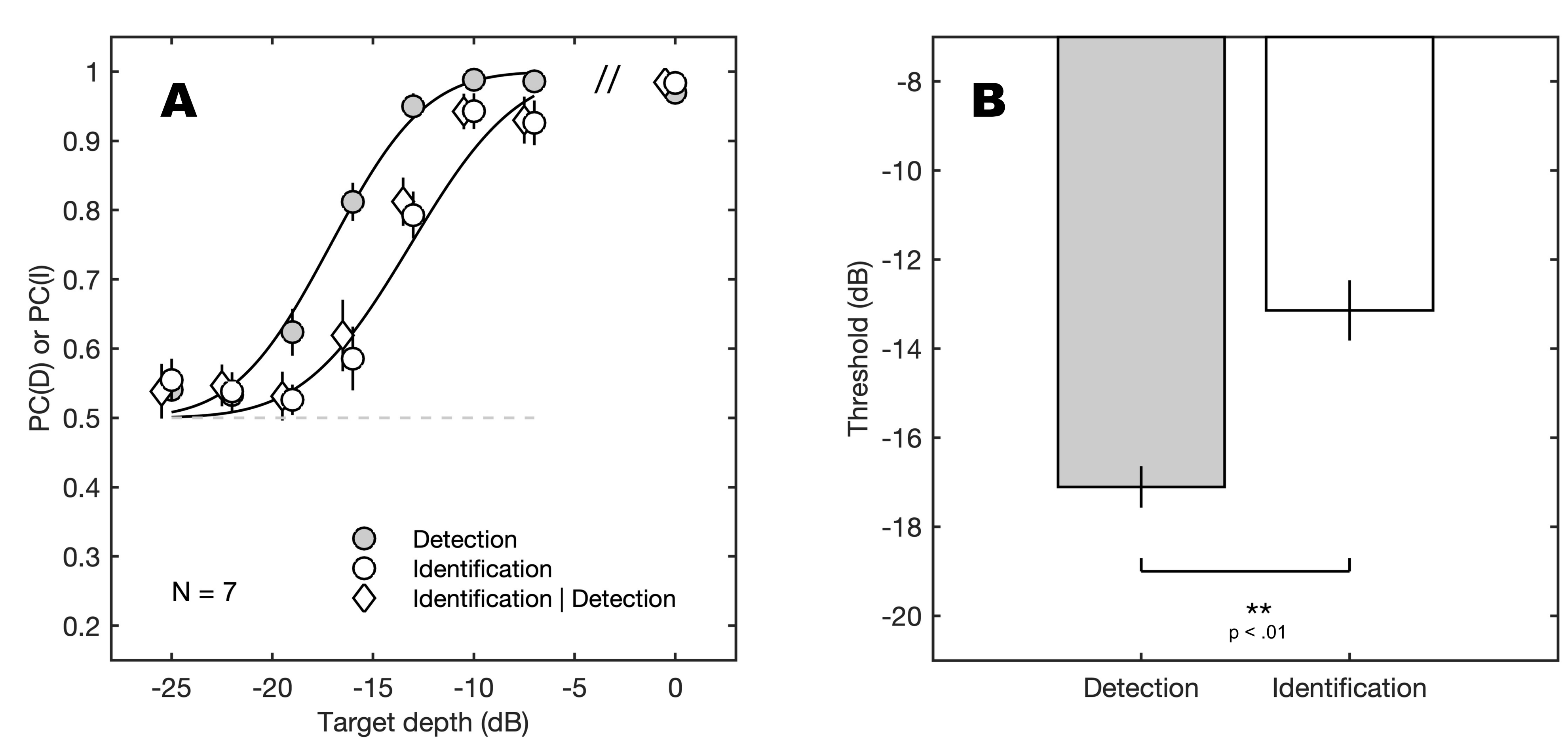

Fig. 2: A: Proportion of correct detection (gray symbols) and identification (white symbols) responses plotted as a function of the modulation depth of the ripples. Each symbol is the average performance across the seven listeners. Error bars are standard errors of the mean. Curves represent the average psychometric functions (Gaussians) for detection and unconditional identification responses. The data for 0 dB were obtained during a training phase and did not contribute to the fits. **B:** Threshold was defined as the target modulation depth required to support a performance level of 0.75. Detection and (unconditional) identification thresholds were obtained for each listener from the fitted psychometric functions. The bars in panel B show the average thresholds across the seven listeners for the two response types. Error bars are standard errors of the mean.

How much overlap between the channels' sensitivities?

The results of the experiment suggest that discrimination between upward sweeping and downward sweeping ripples may be mediated by sensory channels with overlapping sensitivities. The degree of overlap near detection threshold (where tuning is sharpest) can be quantified using Signal Detection Theory [SDT; see Tanner, J. Acoust. Soc. Am., **28**, 882-888 (1956) and Thomas citation given earlier].

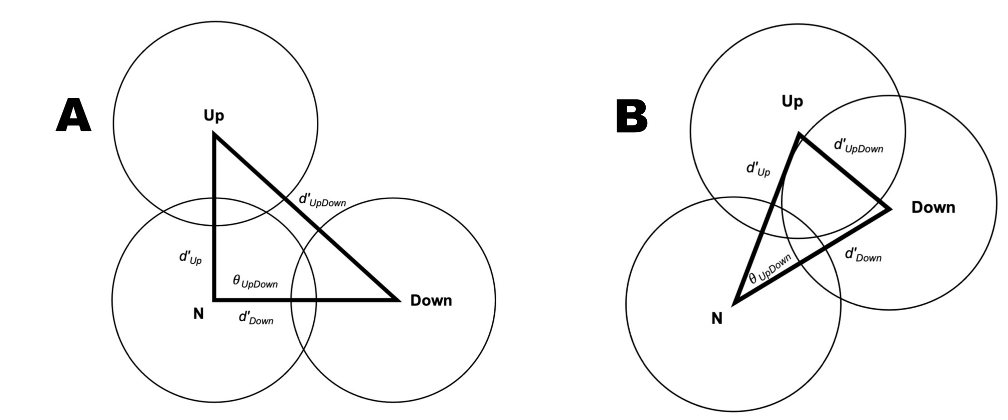

Fig. 3: Theoretical decision space under the assumptions of SDT relating the detection of and discrimination between two ripples with opposite sweep directions. It is assumed that the perception of a particular ripple is mediated by the activity in a channel tuned to that ripple's parameters. **A:** Decision space assuming no overlap between the sensitivities of two channels tuned to opposite sweep directions, but otherwise similar parameters (i.e., spectral and temporal modulation frequencies). Each circle represents the distribution (two-dimensional Gaussian, unit standard deviation) of the decision variable elicited by one of the three stimuli tested: N = noise; Up = upward sweeping ripple; Down = downward sweeping ripple. Assuming equal detectability for the two ripples and no overlap of the channels' sensitivities (i.e., θ_{UpDown} = 90°), SDT predicts sensitivity in the identification task (d'_{UpDown}) that is $\sqrt{2}$ times greater than sensitivity in the detection task (d'_{Up} and d'_{Down}). This works out to equal performance in PC, i.e., is not what we found (Fig. 2). **B:** Decision space assuming substantial channel overlap (i.e., $\theta_{UpDown} \ll 90°$).

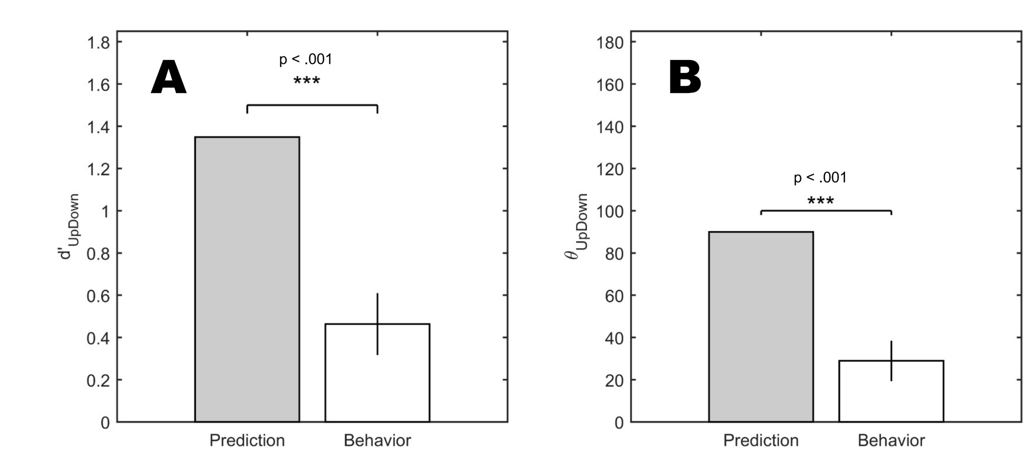

Fig. 4: A: Predicted and observed d'_{UpDown} and **B:** predicted and observed θ_{UpDown} at detection threshold. These data suggest that there is substantial overlap between the sensitivities of the putative channels tuned to opposite sweep directions but otherwise similar ripple parameters. In B, the behavioral result is cos(θ_{UpDown}) = 0.81.

Conclusions

- The results suggest that the discrimination of spectrotemporal ripple sweep direction may not be mediated by independent channels (labeled lines) tuned to different sweep directions.
- Rather, the putative directionally selective channels may have overlapping sensitivities: that is, a channel that prefers upward sweeping ripples may also respond—albeit less strongly—to downward sweeping ripples with otherwise similar ripple parameters.
- Consistent with previous findings [e.g., Oetjen and Verhey, J. Acoust. Soc. Am., **141**, 1887-1895 (2017) and Conroy et al. J. Acoust. Soc. Am., **152**, 1181-1190 (2022], SDT suggests that the overlap between the channels' sensitivities may be substantial.

Acknowledgements
NIH-NIDCD grants No. R01DC004545 and F31DC019819