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LOCALIZATION OF COMPLEX SOUNDS IN THE PRESENCE OF ECHOES

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Most of our knowledge about binaural "precedence effect" comes from studies using dichotic presentations through headphones. The many variants of the most cited technique (Wallach, Newman, & Rosenzweig, 1949) have shown that the second of a pair of dichotic clicks has less effect on lateralization than the first; this generally is interpreted as evidence that, in the open field, echoes are suppressed. Studies of echoes conducted in the free-field suggest a more complicated story. Parameters like duration and onset-time determine the effect of an echoic surface on localization of narrow band stimuli (Rakard & Hartmann, 1985) and such cognitive factors as expectancy can affect the sidedness of sounds presented through two speakers with a delay to one. (Clifton, 1987).

The long range goal of this research is to understand localization of *wideband* stimuli in controlled *echoic environments* using criterion-free *two-alternative, forced-choice* (2AFC) psychophysics. The first data to emerge reported azimuthal sensitivity as functions of azimuth and duration and described post-onset adaptation similar to that found in lateralization with earphones (Hafter et al., 1988). The present study looks at localizations in the presence of single echoes.

METHODS

Signals: The experimental plan is described in Figure 1. Subjects (Ss) sitting in an anechoic chamber discriminated between signals presented from two head-level speakers (marked L and R). The Audax MHD12P25 FSM-SQ speakers were placed 4.5 m from S, symmetrical to the sagittal midline.

Echoes: Phantom echoes from hypothetical echoic surfaces (ES) were produced from speakers (E) placed on a line between the ES and S. There were five echoic surfaces and three directions. For example, the echoic path of signal L to the surface at depth-4 and direction-2 is shown in Figure 1; the echoic stimulus, with appropriate delay and attenuation, was presented from speaker E_2.

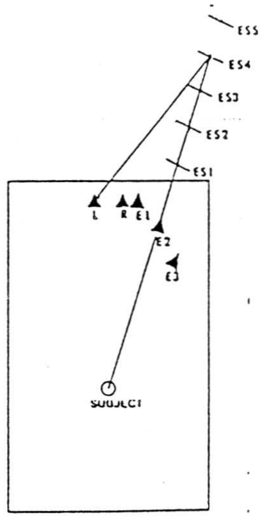

Fig. 1 Stimulus configuration in the anechoic chamber. Primary speakers are marked L & R; phantom echoic surfaces are marked ES; speakers actually producing the echoes are marked E.

Spectral Correction: Studies of spatial discrimination using 2AFC require that there be no difference between sources other than azimuth. Unfortunately, the impulse responses of individual loudspeakers are not alike, which means that in order to enjoy the benefits of 2AFC one must first match the speakers. To this end, inverse digital filters were devised to compensate for spectral differences between speakers. Similar logic has been applied to study tones in the free-field (Leiman & Hafter, 1973) and to present sounds recorded in space through headphones (Poesselt et al., 1986; Wightman & Kistler, 1989).

Stimuli: Signals were filtered acoustic clicks generated by multiplying a 4-kHz cosine times a Gaussian envelope. Click durations were 569 μs between the $\pm 1\sigma$ points; their spectral spread was 1120 Hz at the $\pm 1\sigma$ points. Both direct signals and echoes were computed and corrected with appropriate filters in a PDP-11/73 computer. Echoic delays were included in their computation; their attenuations were set by computer-controlled electronic attenuators. The level of a single click relative to the threshold of hearing was approximately 47 dB SL.

RESULTS

Experiment I: Psychometric functions for discriminations without echoes were obtained with speaker separations of 3.6°, 5.8°, 7.3°, 8.7° and 10.9° of angle. These are shown in Figure 2 for three subjects with performance translated from percentages correct in the 2AFC task to units of d'. The data are well fitted by straight lines. Surprisingly, though, they pass through the abscissa at a positive value (1.82°). This implies a positive acceleration of the relation between d' and angle, and that is not what one might expect given results with headphones that show a <u>decline</u> in accuracy as sounds move away from the midline (Hafter & De Maio, 1975).

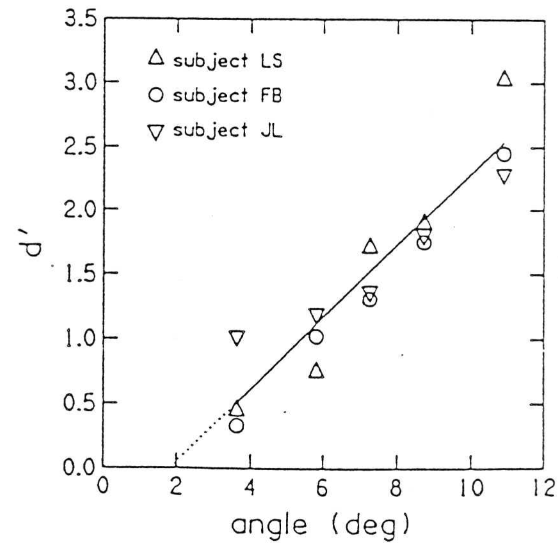

Fig. 2 Psychometric functions for three listeners. The fitted line averages across subjects.

Experiment II: Here the three angular separations that produced d's of approximately 1.5, 2.0 and 2.5 in Experiment I (7.3°, 8.7° and 10.9°) were tested in the presence of echoes. Phantom ES's lay at five different distances in a single direction, 17.8°. Figure 3 shows d's for a single subject (FB); Figure 4 plots the difference between d's with no echo and those with echoes. Results from two other subjects were essentially the same. Ignoring, for the moment, conditions with a short echoic distance, the various ESs produced similar losses in d', differing little across angular separation.

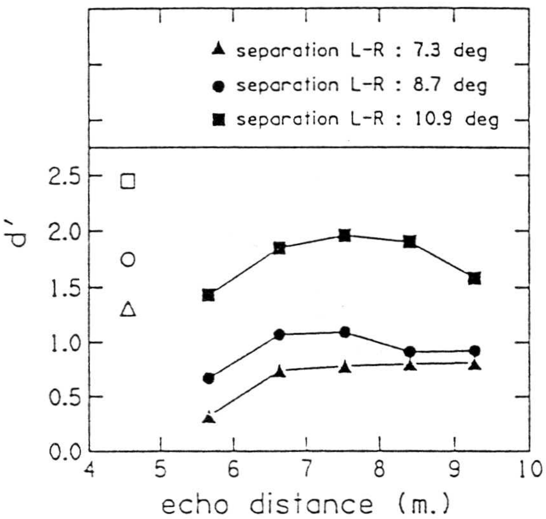

Fig. 3 Performance with no echo (white symbol) and with ESs at an azimuth of 17.8° (black symbol)

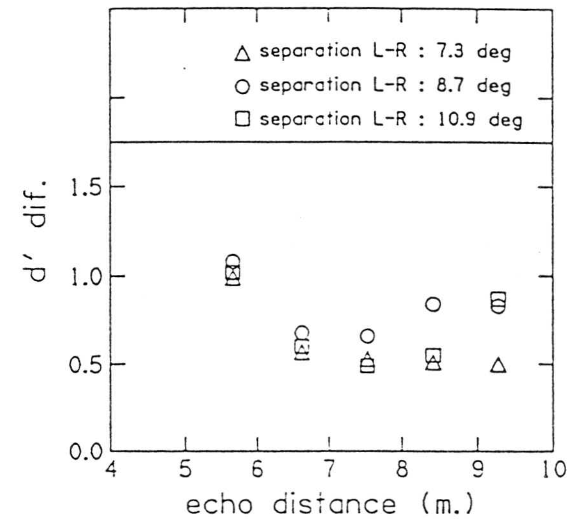

Fig. 4 Data from Figure 3 as replotted as differences $d'_{dif} = d'_{no\ echo} - d'_{echo}$

Experiment III: Here the separation between L & R remained constant at 8.7° but five echoic distances and three echoic directions (7.2°, 17.8° and 28.5°) were tested. Figure 5 shows data from FB. As in Experiment II, the various echoes produced reasonably constant losses in performance with the exception of the close ESs where one condition actually enhanced performance.

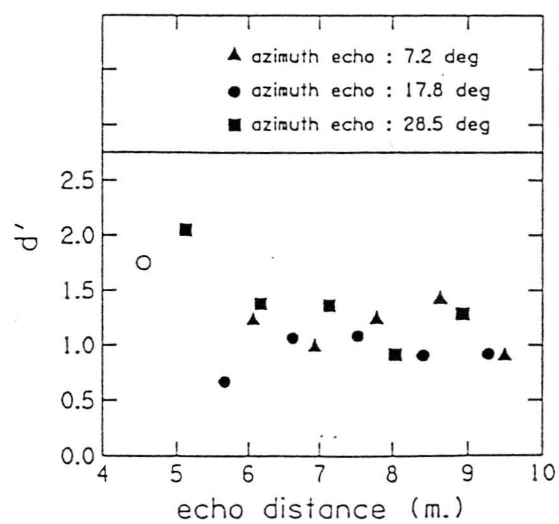

Fig. 5 Performance with ES azimuths of 7.2°, 17.8° and 28.5° marked by black triangles, circles and squares, respectively. The separation of speakers L & R was 8.7°. Performance with no echo is marked by an open circle.

With regard to the fact that the uniformity of loss due to echoes did not extend to smaller echoic distances, we note that Perrott et al. (1989) also have reported especially diverse effects with short echo distances. An adequate discussion of our results with echoes that arrive early, especially those during first few ms of "summing localization" (Blauert, 1974) is beyond the scope of the current paper; quite briefly, though, we have found a myriad of effects ranging from *enhanced separations* of the images to *image reversals*. A full discussion of those results will have to be left for another time.

SUMMARY

Using specially tailored digital filters to make the frequency responses of loudspeakers the same, one can facilitate accurate measurement of localization in the free-field, even with spectrally complex stimuli. Within the conditions tested, we found that echoes from relatively longer distances decreased the discriminability between primary sources by an amount reasonably independent of the direction or distance of the echoic surface. For shorter distances, however, the results were more complex.

In any test with fixed echoic surfaces there is the possibility that listeners may learn to discriminate on the basis of spectral cues in the signal-plus-echo. For that reason, tests currently being run employ echoes whose location is roved on a trial by trial basis. Future experiments using this basic paradigm will utilize multiple echoes as well as cases in which the spectral composition of the echo is modified.

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