ACCURACY IN SOUND LOCALIZATION: INTERACTIVE EFFECTS OF STIMULUS BANDWIDTH, DURATION AND RISE DECAY

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ABSTRACT

This study investigated the effects of stimulus bandwidth/centre frequency (broadband noise vs one-third octave bands, centred at 500 Hz and 4000 Hz), in interaction with stimulus duration/rise decay time (50/10, 300/10, 300/50 and 380/50 ms) on sound localization. The experiment was conducted in a semi-reverberant sound proof booth. Twelve normal-hearing subjects were tested using a single array of six loudspeakers positioned 60 deg apart in the horizontal plane. Each was presented one block of 120 forced-choice speaker identification trials for each for the twelve listening conditions. Subjects achieved 100% correct in localizing broadband noise, regardless of duration/rise decay. Scores were significantly lower for the one-third octave bands. There was no difference due to frequency for the three longer durations. For the short duration/short rise decay, a relative improvement was observed for the low frequency and a decrement for the high frequency. The results were interpreted with reference to the precedence effect.

SOMMAIRE

Cette étude avait pour but d'évaluer l'influence de la largeur de bande et de la fréquence centrale (bruit à large bande, bruits en bande tiers d'octave centré sur 500 Hz et 4000 Hz) sur la localisation auditive, et l'interaction de la durée/temps de montée-descente des signaux acoustiques (50/10, 300/10, 300/50 et 380/50). L'expérience s'est déroulée dans une chambre semi-réverbérante et comprenait un ensemble de six haut-parleurs espacés de 60 deg dans le plan horizontal. Douze sujets avec audition normale ont participé. Chaque sujet devait répondre à une série de 120 essais d'identification de haut-parleur avec choix forcé pour chacune des douze conditions expérimentales. Les sujets ont répondu correctement à 100% des essais dans le cas du bruit à large bande, quelque soit la durée et le temps de montée-descente du signal. Les résultats étaient significativement inférieurs dans le cas des bruits en bande tiers d'octave. Les résultats ne dépendaient pas de la fréquence centrale aux trois durées les plus longues. À la durée la plus courte, une amélioration de la capacité de localization a été observée à la fréquence centrale de 500 Hz et une détérioration à la fréquence centrale de 4000 Hz, par rapport aux trois durées les plus longues. Les résultats expérimentaux sont interprétés en fonction de l'effet de préséance.

1.0 INTRODUCTION

The precedence effect, as described by Wallach, Newman and Rosenzweig (1949), refers to the importance of the direct wave at the onset of the stimulus (first wavefront), relative to delayed reflections from the ongoing portion of the stimulus, in determining the perception of direction in rooms. Tobias and Schubert (1959) studied the relative weighting of these two parameters by means of a sound lateralization paradigm. A noise burst was presented binaurally over a headset, and for a range of interaural onset disparities, the corresponding values of opposite interaural ongoing disparities that centred the acoustic image were measured. The transient onset disparity lost its effectiveness when stimulus duration exceeded 150 ms. For shorter sounds, ongoing disparity was always the more dominant cue, by a factor which was proportional to duration.

In contrast, Kunov and Abel (1981) showed that, for pure tone stimuli, when interaural onset and ongoing fine structure (phase) cues were in opposition, onset completely determined the percept when the rise decay (RD) was brief, i.e., 5 ms. The influence of onset gradually diminished, as RD increased. Not until RD had reached 200 ms, was the perceived laterality of the sound image completely determined by the ongoing phase disparity. The duration of peak amplitude of the stimulus

(25 ms vs 200 ms) was not a significant factor (Abel and Kunov, 1983). Neither onset nor phase was effective for the lateralization of frequencies at or beyond 1500 Hz, except for the shortest RD (i.e., 5 ms). Similiar effects have been shown for localization of pure tones in a sound field. Rakerd and Hartmann (1986) found that onsets as long as 100 ms affected the localization in a semi-reverberant room. RD interacted with the peak intensity of the stimulus, suggesting that the critical variable was onset rate, the increase in sound pressure per unit time.

In a recent study, Giguère and Abel (1993) compared the localization of one-third octave noise bands in absorbent and reverberant rooms. Reverberation compromised accuracy for frontal and lateral speaker arrays, independent of stimulus centre frequency or RD. In contrast to pure tones, the benefit of a short RD was relatively small and limited to the low frequency. A possible explanation was that ongoing random envelope fluctuations in the noise band stimulus diminished the importance of onset.

The present experiment was designed to further investigate the interactive effects of stimulus rise decay and duration, in combination with stimulus bandwidth and centre frequency, on horizontal plane sound localization. The effects of variation in these parameters on the utilization of both binaural and spectral cues in judging directionality were studied.

2.0 EXPERIMENTAL DESIGN

Sound localization was investigated in normal-hearing subjects by means of a single array of six loudspeakers, surrounding the subject at ear level in the horizontal plane. Speakers were positioned 60 deg apart i.e., at azimuth angles of 30, 90, 150, 210 (-150), 270 (-90) and 330 (-30) deg, at a distance of 1 m from the subject's centre head position. The stimuli were broadband noise and one-third octave bands, centred at 500 Hz and 4000 Hz, chosen to allow an assessment of the effectiveness of binaural and spectral cues (Giguère and Abel, 1993).

For each stimulus, four combinations of duration and rise decay time were presented: 50/10 ms (50 ms, including a 10 ms RD), 300/10 ms, 300/50 ms, and 380/50 ms. These contrasted total duration with RD held constant, RD with total duration constant, and duration of peak amplitude with RD constant. The three longer durations were presented at a level of 75 dB SPL and the shortest duration at a level of 82 dB SPL, in an attempt to maintain equal loudness (Miller, 1948; Papsin and Abel, 1988).

3.0 METHODS AND MATERIALS

3.1 Subjects

The subjects were eight male and four female volunteers, aged 21-37 years. Several had previously participated in studies of auditory perception, including sound localization. All had normal hearing bilaterally, with headphone hearing thresholds less than 15 dB HL at 500 Hz and 4000 Hz. Within subject, the difference in threshold between ears was no greater than 6 dB, minimizing the possibility of a right/left bias in sound localization. The experiment was completed in one 2-hr session. Subjects were paid $10 for their participation.

3.2 Apparatus

The apparatus has been described previously (Giguère and Abel, 1993). Subjects were tested individually, while seated in the centre of a 3.5 m (L) by 2.7 m (W) by 2.3 m (H) semi-reverberant sound proof chamber (IAC series 1200) that modelled a real-world listening environment (Giguère and Abel, 1990; Abel and Hay, 1996). Reverberation times for the test stimuli were 0.4 s. The ambient level was less than the maximum allowed for headphone testing (ANSI-S3.1, 1991). Subjects responded by means of a laptop response box comprising an array of six microswitches in the same circular configuration as the speaker array.

3.3 Procedure

One block of 120 forced-choice speaker identification trials, comprising 20 random presentations of the stimulus from each loudspeaker in the array, was given for each of the twelve listening conditions. The order of conditions was counterbalanced across subjects to cancel the effects of practice and/or fatigue. Prior to the start of each block, the subject was given a series of six familiarization trials, comprising one stimulus presentation through each speaker.

A trial began with a 1/2 s warning light on the response box, followed by a brief pause and then the presentation of the stimulus. To minimize the effects of head movement, subjects were instructed to fixate a straight-ahead visual target, to keep the head steady and to sit squarely in the chair, each time the warning light appeared. A maximum of 7 s was allowed for the response. Guessing was encouraged. No feedback was given about the correctness of the judgment.

4.0 RESULTS

Figure 1 shows the mean percentage of correct responses, averaged across the six azimuths, for each of the twelve bandwidth/frequency (BF) by duration/RD (DRD) listening conditions. Standard deviations ranged widely from 2% to 37%, increasing with decreases in accuracy. Regardless of the DRD combination, accuracy was close to 100% for broadband noise. In comparison, subjects achieved 75% correct, on average, when localizing the one-third octave bands, presented using the three longer durations. The short stimulus resulted in a relative increase in accuracy at 500 Hz and a decrease at 4000 Hz.

A repeated measures analysis of variance (ANOVA) was applied to the raw scores (i.e., number of correct responses) obtained for combinations of BF, DRD and azimuth. The data obtained for corresponding right and left azimuths (e.g., 30 and -30 deg) were averaged, since there was no evidence of left/right bias in response for any subject. Standard deviations ranged from 0.4 to 7.3 for the twelve BF/DRD combinations. The one-third octave bands generated values between 5.0 and 7.3. The analysis yielded significant effects of BF, azimuth, BF by azimuth, BF by DRD, and BF by DRD by azimuth ($p<0.01$). By itself, DRD was not a significant factor. Post hoc pairwise comparisons using Fisher's LSD test (Daniel, 1983) to further assess the BF by azimuth effect showed that subjects made significantly more errors when attempting to localize 500 Hz coming from the rearward speaker. In contrast, for the 4000 Hz stimulus, they had greater difficulty localizing sounds emitted by the frontal speaker.

The interaction of BF and DRD was investigated by studying response bias. Figure 2 shows the mean number of trials (out of 120), in which subjects used each of the front (F), side (S) and back (B) response keys for each of the twelve listening conditions. For this analysis, the results for right and left sides were combined. If there were no perceptual bias, then the three keys would be used equally often, i.e., on 40 out of 120 trials. This outcome was observed for the broadband noise.

A repeated measures ANOVA applied to the number of times front, side and back keys were used by each subject for the twelve BF by DRD conditions yielded significant outcomes for response key ($p<0.05$), response key by BF ($p<0.01$), and response key by BF by DRD ($p<0.05$). Post hoc pairwise comparisons of the results for the short stimulus and the average results for the three longer stimuli (which were similar) indicated that for the longer stimulus, the one-third octave band noise centred at 500 Hz was significantly less likely to be perceived as coming from the back than the front and side. The one-third octave band centred at 4000 Hz was significantly less likely to be perceived as coming from the front than the side and back. When the stimulus duration was reduced, the front/side bias for the low frequency diminished by a small amount (4%). In contrast, for the 4000 Hz stimulus, the bias toward the side increased significantly by 9% ($p<0.05$). These changes in perceptual bias likely underlie the observed decrease in the accuracy of localizing 4000 Hz and the improvement for 500 Hz (see Fig. 1), when stimulus duration decreased.

5.0 DISCUSSION

Regardless of duration or RD, subjects had no difficulty in localizing broadband noise. There was no difference due to stimulus duration, RD or duration of peak amplitude. Further, no response bias was evident: front, side and rearward speakers were localized with equal accuracy, suggesting that subjects had the full advantage of binaural and spectral cues for determining location.

Performance was compromised when one-third octave bands were substituted for broadband noise. For the three longer stimuli, subjects achieved 75% correct, on average, regardless of the centre frequency of the stimulus, 500 Hz vs 4000 Hz. There was no effect of RD or duration of peak amplitude. The finding supports the earlier conclusion of Tobias and Schubert (1959) that, in the case of noise bursts, onset loses its effectiveness when the duration exceeds 150 ms. The lack of a frequency effect is in line with Rakerd and Hartmann's (1986) and Giguère and Abel's (1993) contention that subjects are able to use random interaural temporal fluctuations in the envelope to good advantage for sound localization.

Variation in the centre frequency of the one-third octave band did affect accuracy in localizing the short stimulus. An improvement was observed for the lower frequency and a decrement for the high frequency. These effects may be attributable to the short RD, which may have assumed a more dominant role, given the short duration. The frontwards bias observed for the longer 500 Hz stimulus diminished, posssibly because judgments were now determined to a greater degree by the precedence effect. For 4000 Hz, subjects were more likely to use the side key than they had for the longer stimulus, signifying that the ability to distinguish front from back had diminished. In a previous study, front/back discrimination of speakers in lateral arrays was shown to improve with an increase in the centre frequency of one-third octave noise bands, presumably because of the increasing effectiveness of spectral cues from the pinna (Giguère and Abel, 1993). However, front/back judgements are also affected by the precedence effect (Blauert, 1971; Zurek, 1987). Thus, the high-frequency decrement, given the short DRD, in the present study, may have resulted from a conflict between the now stronger onset cue and spectral cues from the filtering effect of the pinna.

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REFERENCES

Abel, S.M. and Hay, V.H. (1996). "Sound localization: The interaction of aging, hearing loss and hearing protection." Scand. Audiol. 25, 3-12.

Abel, S.M. and Kunov, H. (1983). "Lateralization based on interaural phase differences: Effects of frequency, amplitude, duration and shape of rise/decay." J. Acoust. Soc. Am. 73, 955-960.

ANSI-S3.1 (1991). "Maximum permissible ambient noise levels for audiometric test rooms." American National Standards Institute, New York.

Blauert, J. (1971). "Localization and the law of the first wavefront in the median plane." J. Acoust. Soc. Am. 50, 466-470.

Daniel, W.W. (1983). Biostatistics: A Foundation for Analvsis in the Health Sciences, 3rd ed. (Wiley, New York).

Giguère, C. and Abel, S.M. (1990). "A multi-purpose facility for research on hearing protection." Appl. Acous. 31, 295-311.

Giguère, C. and Abel, S.M. (1993). "Sound localization: effect of reverberation time, speaker array, stimulus frequency and stimulus rise/decay." J. Acoust. Soc. Am. 94, 769-776.

Kunov H. and Abel, S.M. (1981). "Effects of rise/decay time on the lateralization of interaurally delayed 1-kHz tones." J. Acoust. Soc. Am. 69, 769-773.

Miller, G.A. (1948). "The perception of short burst of noise." J. Acoust. Soc. Am. 20, 160-170.

Papsin, B.C. and Abel, S.M. (1988). "Temporal summation in hearing-impaired listeners." J. Otolaryngol. 17, 93-100.

Rakerd, B. and Hartmann, W.M. (1986). "Localization of sound in rooms. III: Onset and duration effects." J. Acoust. Soc. Am. 80, 1695-1706.

Tobias, J.V. and Schubert, E.D. (1959). "Effective onset duration of auditory stimuli." J. Acoust. Soc. Am. 31, 1595-1605.

Wallach, H., Newman, E.B. and Rosenzweig, M.R. (1949). "The precedence effect in sound localization." Am. J. Psychol. 52, 315-336.

Zurek, P.M. (1987). "The precedence effect." In Yost, W.A. and Gourevitch, G. (eds.) Directional Hearing. (Springer-Verlag, New York), pp. 85-105.

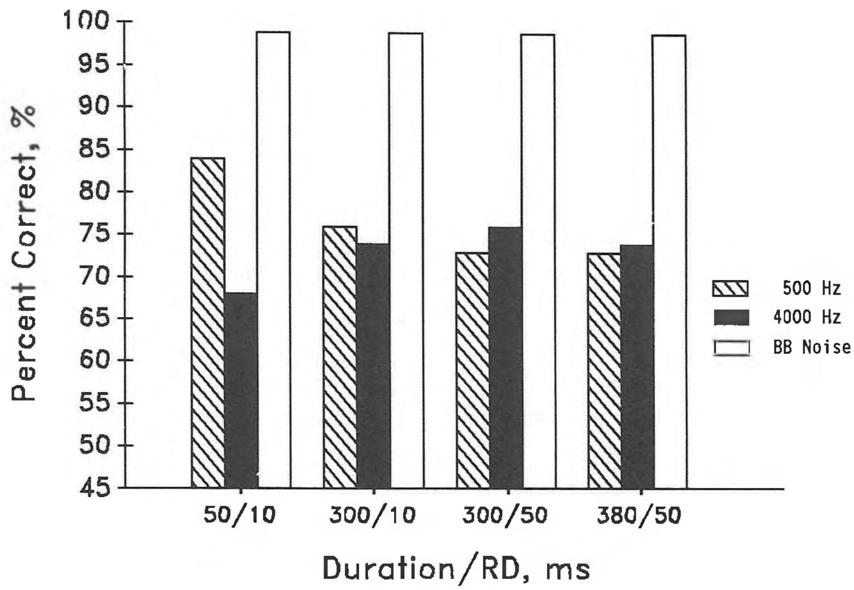

Figure 1. Overall percent correct in sound localization as a function of duration/RD. The parameter is bandwidth/centre frequency.

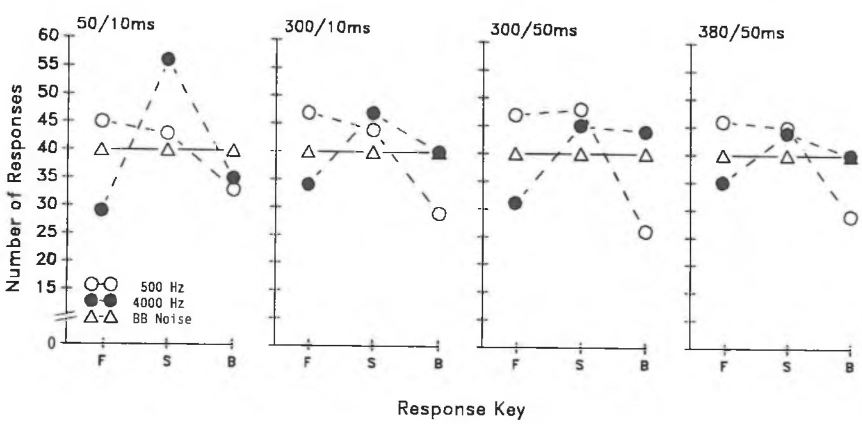

Figure 2. Response bias in sound localization as a function of response key for four duration/RD combinations. Within panel, the parameter is bandwidth/centre frequency.