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SOME BINAURAL FACTORS IN AUDITORY DEPTH ESTIMATION

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ABSTRACT

Two studies using the Gatehouse (1983) paradigm for depth estimation were done. In study I, two "normals", 2 binaurally - and, 2 monaurally - impaired hearers attempted to align 1.0 or 4.0 kHz comparison (Co) tones with a 2.0 kHz fixed position standard (Std). Subjects with binaural hearing-impairments were not much poorer at accurately estimating depth than were monaural or "normal" hearers. The most salient cue to accuracy seemed to be the initial distance (IP; indicative of signal intensities) that the Co was set away from the observer, and from the Std's position, rather than the signals' frequency content. In study II, nine "normal" hearers did the task with signals respectively that were WN as Co and a 1.0 KHz tone as Std, or vice versa. The total Co to Std. distances involved were reduced to 2m. Ss did the task under three conditions: 1) usual sagittal plane entry; or oriented so that signals entry was to their ,2) right (R90) or 3)left ears (L90). Results showed that accuracy under sagittal entry, where presumably binaural cues are minimized, was as good as with left or right ear entries. Unlike our earlier studies, intensity was not (unequivocally) the major cue involved because interactions were observed with both Co content and movement directions. Perhaps WN takes on masking roles with effects that differ as signals are moved closer together.

SOMMAIRE

Deux expériences fondées sur la méthode de Gatehouse (1983) permettant une reconnaissance la gravité de son ont été réalisées. Dans numéro UN, deux sujets "normaux", deux déficients unilatéraux, et deux déficients auditifs bilatéraux, essayèrent de mettre à niveau 1.0 ou 4.0kHz une ton comparison (Co) avec une position standard (Std) fixée de 2.0kHz. En ce qui concerne l'exactitude dans l'estimation de la gravité, les déficients bilatéraux n'eurent pas beaucoup plus de difficultés que les autres sujets. Le facteur pertinent dans la précision semble être la distance initiale (i.e. IP, indicateur de l'intensité du son) Co était fixé loin des sujets et la position et de la standard, plutôt qu'en rapport avec la gamme des fréquences des sons. Dans numéro DEUX, neuf sujets "normaux" travaillèrent sur des tons qui étaient respectivement WN pour Co et 1.0 kHz en std., ou vice-versa. Ces sujets accomplirent l'exercice dans trois conditions d'écoute suivantes: 1) entrée en plan sagittal;ou orientée 2) oreille droite (R90); 3) oreille gauche (L90). Les résultats montrèrent que l'exactitude sous entrée sagittal ou les facteurs bilatéraux sont présumés réduits au minimum, était aussi bonne que sous les autres entrée orientée. Contrairement à nos précédents travaux, incontestablement, l'intensité n'a pas joué le rôle principal car on a observé des interactions significatives tant un plan du Co qu'an plan des directions des mouvements (positif ou négatif) effectués pour la mise à niveau des signaux. Le WN jouerait peut-être le rôle de masque dont les effets différeraient en fonction des mouvements de rapprochement des signaux entre eux.

INTRODUCTION

Since 1909 (Starch & Crawford; Gamble), few papers have been published on acoustic depth perception, and most which have been done, have used classic scaling techniques. That is observers judged or estimated how far away from themselves (or from other arbitrary anchor points) statically positioned, and often, single sources were. There are a few instances of multiple and/ or moving sources estimates. No definitive explanations for depth judgement accuracy have emerged, but following conditions have been studied: interaural intensity cues as a function of distances (Coleman, 1963); spectral and/ or frequency content (Coleman, 1968; Blauert, 1983); head movements (Simpson & Stanton, 1973); median vs aural plane factors (Gardner, 1969); proximity image effects (Mershon et. al., 1980); moving vs static signals (Waugh et. al., 1981); monaural impairment (Gatehouse & Pattee, 1985). Mershon, with several co-authors (1975; 1979; 1980; 1989), has partially modeled the degree to which some of the above conditions contribute absolute (scalar) or relative (non scalar) information depth resolution.

Gatehouse (1983) introduced a depth estimation method which required seated blindfolded subjects to align, or "equate the depth of" an movable sagittal plane comparison (Co) with an alternately sounding fixed position standard (Std) signal. Co and Std signals varied in frequency, were equated in level (db SPL) at Std's position, and were delivered at "0" degrees azimuth and elevation relative to a S's height. Five Initial Positions (IP's) or placements of Co prior to adjustment were tested (+/- 2m; +/- 1m; and "0"). The "0" IP's were "catch" trials where no depth adjustment was necessary to align the sources. Positive (+) positions required movement away from and (-) required movement towards S. At +2m, for instance, Co's IP prior to adjustment was 1m in front of S, 2m in front of Std, and required movement "away from" him/her. Between trials, distance Co was moved (cm) and error (cm) from "true" alignment were recorded. ANOVA's and post hoc analyses were performed on: average movement, average errors collapsed across other conditions, and average ratio data. The latter measure overcomes bias imposed by the varied absolute Initial Positions of Co. Results (Gatehouse, 1983; Gatehouse & Pattee, 1985) suggest intensity differences, as set up by varied IP's of Co from the static Std., were more salient depth cues than frequency differences. Generally however, it was easier to judge depth of lower frequency signals. Movement direction also affects depth accuracy: "away from" results in over-, while movement "towards" observers causes under-estimation of "true" signal depth.

The present studies were done to assess the possible roles of binaural inputs or cues in depth resolution.

METHODS AND RESULTS

Study I: Depth Judgements of Normal, Monaural, and Binaurally-Impaired Hearers

Two subjects in each of 3 hearing conditions (HC; monaural; binaurally-impaired; or binaurally "normal"), as audiometrically and clinically determined, aligned 1.0 or 4.0 kHz Co's, with 2.0 kHz Std. signals. IP's were as in previous studies. After five practice trials with alternating bursts from the 2.0 kHz Std's "0" IP and either of the Co signals, 25 trials were presented i.e. five from each IP. Mixed factorial ANOVA's on 3 (HC) x 2 (Co frequency) x 5 (IP) were done. As in earlier studies, only an IP effect (i.e. intensity) was obtained for average movement and error data but not for ratio data. The latter analysis however, showed a HC x IP interaction ($F=8.14$; $p<.01$). The HC factor was negated by post hoc tests clarifying the IP effects (see Fig.1). Other post hoc tests indicted that binaural and monaural hearers estimated depth about equally well. Binaurally -impaired Ss though somewhat poorer at the task did move the Co in the correct direction towards the Std. Closer examination of directional effects ("0" trials removed), showed that all Ss, regardless of hearing status, underestimate depth in movements "away from self", and overestimate the Std's depth with adjustments "towards self". The exception was the binaurally -impaired Ss at the -1.0 IP.

Study II: Binaural Differences in Acoustic Depth Judgement

In previous studies to limit possible binaural cue differences, Ss made

adjustments facing the speakers along the sagittal plane (0 degrees orientation). However, since Study I had shown no statistical differences between "normal" and impaired-hearer depth acuity, investigation whether "normal's" depth estimation accuracy was enhanced when such cues were more available was done.

Seven "normal" hearing undergraduates performed the task in two phases. In phase one, Co was a WN and the Std a 1.0kHz tone. In phase two the Co and Std signals were reversed. In each phase, Ss made 15 depth judgments (3 x 5 IP's) under three orientation conditions i.e. sagittal plane; 90 L (left ear facing speakers); 90 R (right ear facing). Initial Co positions were now spaced over 2 rather than 4m. (i.e. +/-1m; +/-0.5m; "0"). The design was a within subjects repeated measures factorial: 3 (orientations) x 2 (Co WN with Std a tone; or the reverse) x 5 (IP's). For the first time using this paradigm, the three measures results were not consistent and IP saliency not foremost. For movement measures, Co signal ($F=6.46; p<.05$), IP ($F=4.24; p<.05$), and an all factor interaction ($p<.05$) were found. Tukey HSD tests on positions across orientations were not significant, but IP's differed across signals. Apparently, the interaction was introduced by WN use, although it was limited to sagittal and 90 R orientations and at the +0.5m IP. ($F=10.89; p<.05$). The "errors" ANOVA corroborated Co significance ($F=18.2; p<.05$), but the only interaction was IP x orientation ($F=26.6, p<.01$). Post hoc examinations of the joint effects of Co's and IP's demonstrated that WN terminal placements were always "beyond" the Std, and except for -1.0m IP, always in front of the Std for the tone. With ratio scores, IP was again significant ($F=4.5; p<.05$) along with a Co x IP x orientation interaction ($F=15.3; p<.01$). Fig.2 shows the interaction and indicates greater movements were observed for tones initially aft of than fore of the Std, while the opposite was noted for WN stimuli. Finally, when ratio means were collapsed across orientations, the IP effect remained.

DISCUSSION

Apparently, within this paradigm, binaural cues may not greatly affect accurate acoustic depth judgements. In Study I normal and non-normal hearers were not significantly different with presumably reduced binaural cues (sagittal plane entry), and even binaurally -impaired hearers were not greatly debilitated. At worst, the latter Ss' absolute "errors" were greater, and they had a different pattern of depth accuracy (ratio data Fig. 1). In Study II, normal hearers were no better judging depth with more maximal binaural cues available (90 L & R entries). In fact, overall it seems that depth is more easily resolved along the sagittal plane (Fig 2, open and filled circles) where binaural cues are presumably minimized.

Previous evidence using this paradigm, until Study II here, had consistently suggested that acoustic depth judgement accuracy was accomplished by a comparison of the intensities, as relative cues, of the tonal signal. The static Std was always an unchanging anchor point against which to make the comparison, and frequency although a non significant factor, perceptively helped keep the different intensity signal separable. However, broadband signal introduction apparently makes the judgement process more difficult because frequencies become highlighted and it is more difficult to attend primarily to relative intensities. Usual tendencies/strategies to over- and underestimate distances from positions respectively in front of, and aft of an anchoring point no longer work. In short, more factors (here, WN and tonal signals; IP's; and movement direction) enter the judgement process. For example, WN may begin to be a masker as signals approximate. Perhaps too, the shorter total observation distances (2m) used here also helped negate the intensity cue differences. Such speculations seem to support the Mereshon et al's (1989) model of depth resolution as fine interplay of identifiable relative and absolute cue values. However, given the interaction of factors here, and the possibly masking role of WN, it is not as easy as the model implies to indicate which cues carry which information type.

Figure 1

Fig.1: Mean Ratio Scores for Initial Positions (0 degree position removed) by Hearing Condition collapsed across comparison frequencies

Figure 2

Fig 2: Mean Ratio Scores for Initial Positions (0 degree position removed) by Comparison Signal (Tone; WN) and Orientation

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