Effects of Forward/Backward Head Position on Judged Auditory Direction

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INTRODUCTION

At least three factors have been shown to control judged clockwise (CW) or counterclockwise (CCW) direction of two tones each emanating from a different location on an azimuthal circumference (Cohen, Lamothe, MacIsaac, Fleming, & Lamoureux, 2001). First *proximity* of the two sources governs the judgment such that the directed vector takes the shortest distance between the two sound sources. (A similar finding in the pitch domain has been observed by Shepard, 1964). Secondly, if listeners tend to hear sounds from only the front or back hemisphere, sources of tones in the ignored hemisphere will be re-located to the mirror-imaged position in the preferred hemisphere. This common phenomenon of *front-back confusion* was early described by Toole (1970). Finally, a small but significant tendency for a *clockwise bias* causes listeners to hear tones move in a CW direction more than would be predicted by the other two factors. This last factor is particularly evident for trials containing two locations that are separated by 180-degrees, because in this case the first factor cannot provide proximity cues.

The present study focuses on the role of front-back confusion and examines specifically the listener's nearness to speakers ahead or behind. In our previous studies, the listener sat in the centre of the circle but position of the head with respect to the speakers (ahead and behind the head) was not controlled. Some listeners may have positioned their body more within one hemisphere than the other. This possibility leads to three hypotheses. First, because greater immersion of the head within one hemisphere increases the intensity of the speakers in that hemisphere, hearing of all sounds will be biased to that hemisphere. Secondly, because greater immersion within one hemisphere increases the time and intensity cue differentiation between front and back speakers, this increased differentiation will assist in creating a 360-degree acoustic space. Third, for listeners who have a location bias to one hemisphere or another when centred in an array, positioning the body in the unpreferred hemisphere and the consequent cue differentiation may correct this bias and create the 360-degree space.

In the present study, to test these hypotheses and to increase our understanding of the effect of forward/backward head position on CW and CCW auditory motion direction judgments, an experiment was conducted in which listeners made CW/CCW judgements about auditory direction in three conditions that differed in location of the listeners who were either centred within the circular array of speakers or were positioned one foot ahead of centre or one foot behind.

METHOD

Subjects. There were 4 male and 2 female subjects ranging from 18 to 21 years of age. Hearing level, tested with Digital Recordings AUDIO-CD™ was within normal limits in the range 1000 - 4000 Hz.

Apparatus. In a single-walled sound-attenuated room (Eckel), 12 small Koss speakers (12 x 8 x 8 cm) were spaced at intervals of 30- degrees around an azimuthal circumference of the largest circle (diameter = 119 cm) that could be accommodated by the room. The speakers were 1.5 m off the floor, roughly at ear level for an individual seated in the centre of the circle. Two speakers were suspended from each of three walls, however, because the room was slightly rectangular speakers on the back wall sat on a shelf. The 4 remaining speakers were supported independently on metal stands. A multiplexing switch directed an audio signal to one of the 12 speakers. The signal was a complex tone composed of 10 octaves of 22.5 Hz with an envelope that approximated a Gaussian function. Each signal was 250 ms in duration.

Procedure. Listeners were tested individually, seated within the circumference of the 12-speaker array. In a block, each listener was presented with (12 x 11 =) 132 pairs of successive tones, such that all possible successive pairs of the 12 speakers were represented. The intertone interval within a trial was 450 ms. On each trial, the listener was requested to judge the direction of the sound around his or her head represented as two choices (CW or CCW) on a computer screen. The listener clicked a mouse to make the selection and this initiated the next trial automatically. The block of trials took about 10 min. There were 3 successive blocks in a session, such that each pair was represented 3 times for a total of 396 trials. Each listener received 3 sessions (1.5 hr of testing).

For each of the three 396-trial sessions, the listener sat in a different position relative to the circle, either in dead centre, or one foot ahead or behind this position (a movement along the line joining diagonal corners of the room). The listener always faced the same direction–a corner of the room— and used a cordless mouse, on a bench positioned near him or her, in order to affect the screen at the various distances away from it. Each of the 6 listeners received a different order of the positions, such that all possible orders were represented by the subjects (i.e., ahead, centre, behind; ahead, behind centre; centre ahead, behind, etc).

RESULTS

Direction as a function of CCW rotation. Considering the CW movement only, the trials represented 12 different sizes of spatial intervals, the smallest (1 unit) arising from presentation of one of the 12 tones, followed by the speaker to its adjacent right. The distance of 2 units was represented by pairs in which the 2nd speaker was 2 speakers to the right of the speaker that presented the 1st tone of the trial. The distance of 11 units was represented by pairs whose 2nd speaker was 11 tones CW from the first tone presented (i.e., just 1 unit away CCW). For each session of 396 trials, for each individual, the number of clockwise judgments for each of the 12 clockwise distances was calculated. The mean percentage of clockwise judgments is shown in Figure 1. It can be immediately seen that the number of clockwise judgments is a continuous function of distance and mirrors the pattern of directional judgments for circular pitch of Shepard (1964).

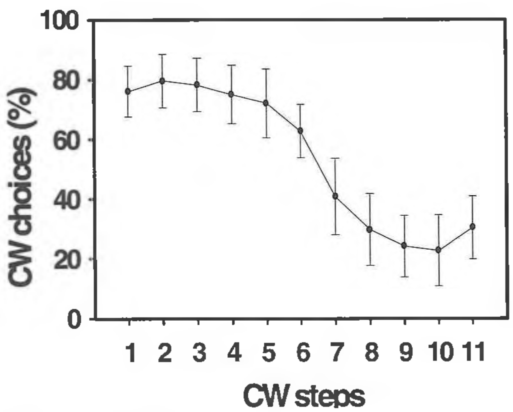

FIGURE 1. Mean percentage of CW judgments and SD as a function of CW step size collapsing over all sessions and subjects.

Front back confusions. An 11 x 12 matrix of CW or CCW judgements for each of the three blocks of data for each subject was compiled with a CW judgement given the value 1 and a CCW judgment given the value -1. These data were correlated with each of three templates of judgment based on the proximity rule (smallest distance governs the choice) and differing in the extent and type of front-back confusion. Template 1 (Circular) had no front-back confusion and assumed the location of all speakers was judged veridically. Template 2 (Front) represented the listener who heard tones emanating only from the speakers in the front hemisphere, with sounds from the back hemisphere heard as coming from the position mirrored in the front hemisphere. Template 3 (Back) represented the listener who heard tones only in the back hemisphere. A correlation of the actual data with the templates led to 3 correlation coefficients for each subject (however Templates 2 and 3 were different only in sign, and Template 3 will not be specifically referred to again). For each subject at least one of these correlations was statistically significant. Where correlations were high for one template, they were lower for the other.

For all listeners the Circular Template provided a better fit to the data when listeners were seated closer to the front speakers. For the majority of the listeners, changing proximity to the speakers by one foot changed the goodness-of-fit of the template. For only one listener, was the circular template the best-fit for all three locations. For three of the listeners the back position led to a best-fit with the Back Template, but for one listener in the back position, the best fit was the Front Template. For two listeners, the centre position was characterized by a Front Template for one listener, and a back template for the other.

The mean correlation obtained with the Circular Template for all six subjects for the ahead, centre, and behind positions was .73, .55 and .44 respectively. Thus, the appropriateness of the Circular Template is greatest for the in-front-of-centre position, and is least appropriate for the behind-centre position. To determine whether these differences were significant, for each subject, the correlation derived from the circular template was entered into a repeated measures ANOVA having one factor of seating position having three levels (ahead, centre, behind). The effect of body position was significant, $F(2, 10) = 7.20$, $p < .012$, attributable to a linear trend, $F(1, 10) = 22.9$, $p < .005$. A similar analysis of correlations for the Front Template did not produce significant effects.

DISCUSSION

The present study illustrates that a relatively small change of a listener's position within a circular array can reverse the perceived direction of auditory motion. The result is explained by an increase or decrease in front-back confusion, with trials whose direction is switched being those with one or two speakers in the non-preferred hemisphere (i.e., if the listener hears all tones in the front, then a tone presented from a speaker in the back hemisphere will be heard as coming from its mirror image location).

The most important finding however is the fact that, at least in these conditions of testing, the most veridical hearing, that is, hearing without front-back confusion, and hearing in a full 360 degrees arises for five of the six listeners when they are not in the centre of the circle, but rather one foot forward. Moving ahead must be compensating for a tendency to hear the speakers in the back when one is truly centred. In spite of this general trend in the data, there were wide individual differences. These results have practical implications for those who would create impressions of spatial auditory vectors, in real-world surround-sound environments, such as home and public theatres.

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Acknowledgements and author notes.
The research was supported by an NSERC Operating Grant to A. J. Cohen. The assistance of Robert MacIsaac who tested the subjects and of Robert Drew and Ian Toms who assisted in calibration is acknowledged. The multiplexing switch was developed by Michael Lamoureux and adapted by Richard Fleming.

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