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Perceptual judgments with discrepant information from audition and proprioception*

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Fifteen blindfoleded Ss judged the spatial orientation of a bar, which rotated in the horizontal plane, by using proprioceptive and/or auditory information. Judgments were made when information from the two modalities was made to yield the same or conflicting spatial orientations of the bar. Both modalities were individually capable of providing equally accurate judgments, yet, when an auditory-proprioceptive discrepancy was introduced, auditory judgments were strongly biased by proprioceptive input. Proprioceptive judgments were only minimally influenced by conflicting auditory information.

Information concerning the spatial location of objects in the environment or parts of one's body can be provided by vision, audition, and proprioception. Typically, two or all three of these sensory modalities operate simultaneously in spatial perception. As a means of studying the roles of the different modes of sensory information in perception, an experimental method has been employed in which input from one modality is made to yield information which is discrepant with that from another modality. Perceptual judgments under such conditions of intermodal discrepancy provide some indication of the relative importance of one sensory modality vs another in making such judgments.

Most of these experiments have dealt with perception under conditions in which vision was made to yield discrepant information with either audition or proprioception. In most of these studies, perception was greatly or completely biased in favor of visual information (for visual bias of proprioception: Gibson, 1933; Rock & Victor, 1963; Hay et al, 1965; Klein, 1966; Pick et al, 1969; for visual bias of audition: Young, 1928; Thomas, 1941; Witkin et al, 1952; Pick et al, 1969). A recent exception to the apparently ubiquitous dominance of vision was provided by Warren and Cleaves (1971), who found that, under certain circumstances, proprioceptive information could bias visual judgments to a considerable extent.

Unfortunately, only two studies have dealt directly with perception under conditions of discrepant information from audition and propriopception. Fisher (reported in Howard & Templeton, 1966) told Ss that stimuli from different pairs of modalities were in the same spatial locations. The locations of stimuli from one modality were then made to differ, and S pointed to what he believed to be the single location of the stimulus pair. It was found that auditory judgments tended to comply with proprioception. A recent study by Pick, Warren, and Hay (1969) used a pseudophone to introduce an 11-deg displacement of the interaural axis and had Ss point to auditory targets. Speakers mounted on pegs provided auditory cues for localization. Ss were required to point with one hand at the "felt" position of their other hand when it was touching the displaced sound source. In the same manner, they were required to point to the "heard" position of the speaker touched by the opposite hand. Results of this experiment indicated that auditory judgments were biased by discrepant proprioceptive information, with little or no effect of auditory input on proprioceptive judgments.

The latter two studies suggest that proprioception biases auditory judgments to a large extent. The nature of this relationship, however, is in need of clarification. It is possible, for instance, that other types of auditory and proprioceptive tasks may result in different degrees of biasing of one modality by another. In the Pick et al study, for instance, *pointing* was used to provide proprioceptive information, and a pseudophone was used in providing auditory information. Such a situation would seem to favor proprioception from the outset, since, in "every-day life," pointing is a common and well-practiced method of indicating spatial direction. Furthermore, it has been this E's personal experience that pseudophones provide quite an unnatural experience of auditory events. The present study was designed to create an auditory-proprioceptive discrepancy without pseudophones, and used a different kind of perceptual task to determine the effect of the discrepancy upon S's judgments.

METHOD

Subjects

Fifteen U.S. Navy male Submarine Service candidates served as Ss.

Apparatus

The apparatus was designed to allow Ss to make judgments of the angle of a bar in the horizontal plane by using proprioceptive and/or auditory information.

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Table 1

	A	P	P(A)	A(P)
Errors in Judgments With Auditory Axis Not Shifted*				
Mean	−0.6	−0.9	0.2	−0.2
SD	4.1	2.4	3.0	2.0
Errors in Judgments With Auditory Axis Shifted*	A†	P	P(A)†	A(P)
Mean	3.8	−1.0	12.5	−1.7
SD	6.9	1.9	7.9	3.1

Note—A = auditory judgment, no proprioceptive input; P = proprioceptive judgment, no auditory input; P(A) = auditory judgment with proprioceptive input; A(P) = proprioceptive judgment with auditory input.
**In degrees of angular rotation from the perfect judgment.*
†Perfect judgment = −18 deg (for all other judgments, perfect judgment = 0 deg.

The bar was a 1 x 2 x 48 in. piece of wood which could be rotated freely at its midpoint on a 6-in.-tall vertical axis upon a table. The angle of the bar in the horizontal plane, relative to a protractor mounted at the apparatus's base, could be measured by a pointer attached to the underside of the bar and pointing to the protractor.

Two TDH-39 earphones were mounted on 14-in.-long slotted lengths of wood, which in turn were fastened to the horizontal bar with bolts and wing nuts. By adjusting the positions of the earphone mounts, the earphones could be made to coincide with the ends of the bar or to extend in opposite directions from the ends of the bar. The phones were driven by a Grass stimulator, which generated clicks (frequency 17/sec, duration 1 msec) at a comfortable listening level and were activated at alternating .67-sec intervals by a Grason-Stadler electronic switch.

The 0-deg angle of the protractor corresponded to a plane parallel to the frontal plane of S's body when S was seated in a chair placed perpendicular to the apparatus's 0-deg angle, and S's chin and head were placed in a rest also perpendicular to the apparatus's 0-deg angle. This angle (0 deg) will be referred to as the frontal angle.

Procedure

All experimentation was performed in an anechoic chamber at the U.S. Navy Submarine Base Medical Research Laboratory in New London, Connecticut. Ss were blindfolded for testing.

Instructions and Practice

S was familiarzed with the workings of the apparatus and instructed that his task would be making judgments of the frontal angle, which was described to him, by using audition and/or proprioception.

The sound sources, in a position coinciding with the ends of the bar ("nonshifted"), were activated, and S was told that the angle of the bar in relation to his body could be determined just by listening to the spatial locations of the sound sources.

Next, S was shown how to hold the bar to use proprioceptive information about its orientation in relation to his body. To adjust the bar, S was instructed to use both hands to grasp the bar on tape marks 10 in. from either side of the bar's midpoint.

A 3-min practice period followed, in which S made judgments of the frontal angle, using both proprioceptive and auditory information.

Judgments

In a randomized order, each of the following judgments of the frontal angle was made by blindfolded Ss three times. The initial angle of the bar was varied randomly for each judgment.

(1) *Auditory judgments with no proprioceptive information present (A judgments).* S placed his hands on his lap; the sound sources (in the nonshifted position) were activated; and S instructed E on how to move the bar to reach the frontal angle of the line connecting the two sound sources (the auditory axis).

(2) *Proprioceptive judgments with no auditory information present (P judgments).* The S rotated the bar himself, without sound, and adjusted the bar to the frontal angle.

(3) *Auditory judgments with proprioceptive information present [P(A) judgments].* With the nonshifted sound sources activated, S rotated the bar and positioned it so that it "sounded" as if it were in the frontal angle. S was instructed to make his judgments according to the sound sources and to ignore what the position of the bar "felt like."

(4) *Proprioceptive judgments with auditory information present [A(P) judgments].* With the nonshifted sound sources activated, S positioned the bar so that it "felt like" it was in the frontal angle, ignoring what the position of the line connecting the phones "sounded like."

When these judgments had been made, the auditory axis was, unknown to S, rotated 18 deg in the horizontal plane by extending the sound sources in opposite directions from the ends of the bar, maintaining a constant distance between the sound sources ("shifted position"). The "proprioceptive frontal angle" remained at 0 deg when the S moved the bar, while the "auditory frontal angle" was −18 deg, since it was at this angle that the imaginary line connecting the two sound sources would be 0 deg. In other words, there was an 18-deg discrepancy between the bar angle (indicated by proprioception) and the line connecting the sound sources (indicated by audition). Again, in a randomized order, S made the same four types of judgments three times each with the auditory axis shifted.

RESULTS AND DISCUSSION

To comparejudgments under different conditions, the errors in judgment of the auditory or proprioceptive frontal angles were examined. The perfect judgment of the proprioceptive or nonshifted auditory frontal angle would be 0 deg, while the perfect auditory judgment of the shifted auditory axis would be −18 deg. Positive valued errors indicate a judgment clockwise from the true angle (toward 0 deg with respect to the shifted auditory axis) and negative valued errors indicate judgments counterclockwise from the true angle (toward the angle of the shifted auditory axis with respect to 0 deg). Table 1 shows mean errors in judgments for each condition.

Judgments Made Without Auditory-Proprioceptive Discrepancy (Control Tests)

When the auditory axis was not shifted, neither the difference between errors of A judgments (auditory with no proprioceptive input) and P(A) judgments (auditory with proprioceptive input) nor the difference between errors in P judgments and A(P) judgments (proprioceptive with auditory input) were statistically significant. These control tests indicate that, under the present conditions, there is no evidence that consonant information from either modality affected errors in judgments made using the other modality.

A judgments of the shifted auditory axis tended to be somewhat less than the actual −18 deg (Table 1).

Comparing the errors from −18 deg in A judgments of the shifted auditory axis to the errors from 0 deg in the nonshifted A judgments shows that the errors in judging the shifted auditory axis tended to be toward the frontal (0 deg) angle (Table 2, A−A-s). The reason for this is unclear, but is probably not of great importance in the present experiment.

Effects of Shifting the Auditory Axis

Influence of Proprioceptive Input Upon Auditory Judgments of Shifted Auditory Axis

Table 2 shows that errors in P(A) judgments (auditory with proprioceptive input) of the shifted auditory axis were greater than errors in judgment of the nonshifted auditory axis by 12.7 deg ($t = 7.80$, $p < .001$) in the direction of the proprioceptive frontal angle. Thus, when discrepant proprioceptive information was present, the auditory axis was auditorily judged to be closer to the proprioceptive angle than to the auditory angle, indicating a strong biasing of auditory judgments by discrepant proprioceptive input.

Influence of Shifted Auditory Input Upon Proprioceptive Judgments

The effect of shifting the auditory axis upon proprioceptive judgments was determined by comparing errors in A(P) judgments (proprioceptive with auditory input present) with the auditory axis in the shifted vs nonshifted positions. Table 2 shows that there was a small increase in errors of −1.5 deg ($t = 2.24$, $p < .05$) for A(P) judgments when the auditory axis was shifted. It appears that auditory information biased proprioception, but the effect was small under these conditions.

The results of the present study agree with previous findings using pseudophones and other perceptual tasks: auditory judgments are heavily biased by discrepant proprioceptive input, while proprioceptive judgments are minimally, if at all, biased by discrepant auditory information. Mention should be made of a fundamental difference in the auditory-proprioceptive discrepancy with the present method as opposed to the pseudophone method. In the latter, all auditory input is spatially distorted, while in the former, only the auditory axis with respect to the bar is affected. The consequences of this difference should have been minimized, however, for several reasons. By testing in an anechoic chamber, stray sounds, echoes, etc., were eliminated; the testing apparatus was designed so as not to make any undesired noise; the Ss' hands were placed on the bar before activating the sound sources, thereby eliminating the sound of the hands meeting the bar as a cue. It would seem a reasonable assumption, then, that the only significant auditory and proprioceptive cues were provided by the apparatus as desired.

Table 2

Comparison of Errors	Degrees Difference
Comparison of Errors in Judgments When No Discrepancy Between Modalities Existed	
A−P(A)	−0.7
P−A(P)	−0.3
A−A-s	4.4**
Comparison of Errors in Judgments When Discrepancy Between Modalities Existed	
P(A)-s−P(A)	12.7†
A(P)-s−A(P)	−1.5*

Note—A = auditory judgment, no proprioceptive input; P = proprioceptive judgment, no auditory input; P(A) = auditory judgment with proprioceptive input; A(P) = proprioceptive judgment with auditory input; -s = auditory axis shifted.
*df = 14 for all t tests *p < .05 **p < .01 †p < .001*

It would appear that greater accuracy of proprioception in performing the task cannot account for the bias effect. Table 1 shows that there was a difference of only 0.3 deg between A judgments and P judgments, which was not statistically significant. Also, a t test for variances between samples (Glass & Stanley, 1970) indicated no statistically significant difference in variance between the two types of judgments. Indeed, every attempt was made to maximize the accuracy of auditory judgments. Alternating trains of clicks from two well-separated sound sources provided excellent cues for interaural differences in intensity and time of arrival, both of which are implicated in auditory spatial localization. Further accuracy was provided by testing in an anechoic chamber and without the use of pseudophones.

None of the Ss were aware that an auditory-proprioceptive discrepancy had been introduced when questioned after testing. Indeed, most were surprised when informed of what had been done. It would appear that proprioceptive input distorted auditory perception in a very effective manner. Thus, taken together with previous works, it seems that auditory localization can be strongly distorted by proprioceptive input, whereas the converse does not obtain.

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