Lateral-position-based models of interaural discrimination

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(Received 29 July 1983; accepted for publication 20 September 1984)

This letter investigates the hypothesis that lateral position is the only cue available for interaural discrimination experiments using 500-Hz stimuli. The discussion of this hypothesis is in the context of comparisons of the experimental data to predictions of the "position-variable" model of binaural interaction. The model predicts the mean and variance of the subjective lateral position of stimuli used in the discrimination experiments, assuming that discrimination performance is based on optimal processing of this subjective position. To the extent that the laterality predictions of the model are accurate, data that are inconsistent with its predictions would also be problematical for any model based on the subjective laterality of a single binaural image. The predictions (at least qualitatively) describe much of the observed experimental data, including a number of results that have not been addressed by any previous theory. Nevertheless, the observed performance is significantly better than the corresponding predictions for three types of experiments in which the utility of the position cue has been eliminated by experimental design. We believe that our results indicate that changes in lateral position are the primary cue in most interaural discrimination experiments, but that secondary attributes of the perceptual images can be useful when performance based on position alone would be poor.

PACS numbers: 43.66.Pn, 43.66.Ba, 43.66.Rq [FLW]

INTRODUCTION

Subjective lateral position is a prominent cue in many psychoacoustical experiments in which interaural time differences (ITDs) or interaural intensity differences (IIDs) are varied. For example, Klumpp and Eady (1956), Hershkowitz and Durlach (1969), Yost (1974), and Domnitz and Colburn (1977) have all specifically cited the use of lateral position cues in their experiments measuring just noticeable differences (jnds) of ITD or IID. Theoretical studies comparing various interaural discrimination results to changes in subjective position include work by Hafter and Carrier (1970), Hafter (1971), Yost (1970), and Domnitz and Colburn (1977).

In this letter we investigate the hypothesis that lateral position is the only cue available (other than pitch and loudness cues) for binaural experiments in which subjects discriminate 500-Hz stimuli presented with slightly different ITDs and/or IIDs. The discussion of this hypothesis is in the context of the "position-variable" model (Stern and Colburn, 1978) which predicts the subjective lateral position, and its variability, of the single dominant image of the stimuli used in these interaural discrimination experiments. The model assumes that discrimination performance is based on the optimal processing of this subjective position. This approach has previously been used in applying the theories collectively referred to as "lateralization models" to tone-on-tone masking results (Hafter and Carrier, 1970; Yost, 1970), and interaural time and amplitude jnds (Domnitz and Colburn, 1977). Most of these models (e.g., Hafter and Carrier, 1970; Yost, 1970) have assumed that the lateral position of the dominant subjective binaural image can be modeled as a linear combination the the ITD and IID of the stimulus, and that the variability of this subjective lateral position is independent of the stimulus ITD and IID. According to available data on subjective lateral position (Sayers, 1964; Domnitz and Colburn, 1977; Yost, 1981), the former assumption only applies (for 500-Hz stimuli) to IIDs of approximately 0 dB and ITDs of approximately 0 or ± 1000 μs. For these ITDs and IIDs, all models provide the same description of lateral position, and predictions developed in the present paper apply generally to all models. For ITDs and IIDs outside this range of values, the linear description of position is inappropriate and predictions of the simple lateralization models have generally not been applied to the available data.

To the extent that the laterality predictions of the position-variable model are accurate, discrimination data that cannot be described by this model would also be problematical for *any* model based solely on the subjective lateral position of the dominant binaural image. Hence, we consider a comprehensive review of the successes and failures of the model in predicting results from interaural discrimination experiments to be worthwhile, even though many of the comparisons are similar to results obtained in previous studies.

 0001-4966/85/020753-03$00.80

I. SUMMARY OF COMPARISONS OF PREDICTIONS AND DATA

The position-variable model characterizes the subjective lateral position of a 500-Hz stimulus by the random variable $\hat{P}$, which is assumed to be derived from the stochastic auditory-nerve response to the sound (Stern and Colburn, 1978). $\hat{P}$ is specifically assumed to be normally distributed, with a mean and variance that depend on the ITD and IID of the stimulus. Predictions for the results of various types of interaural discrimination experiments were obtained by calculating the value of the independent stimulus variable that would produce threshold discrimination performance. These predictions are described in detail in Stern and Colburn (1985).[1] Free parameters of the model were fitted on a subject-by-subject basis in some of these experiments so that the predicted absolute sensitivity of the model and the model's effective time-intensity trading ratio would best describe the experimental data. The experiments to which the model was compared include the interaural time-jnd measurements of Hershkowitz and Durlach (1969), Domnitz (1973), Yost (1974), Domnitz and Colburn (1977), and Moss (1979); the interaural amplitude jnd measurements of Rowland and Tobias (1967), Hershkowitz and Durlach (1969), and Domnitz and Colburn (1977); coherent tone-on-tone and noise-on-noise masking studies, with detailed comparisons to the results of Yost *et al.* (1974) and Jeffress and McFadden (1971); and the time-intensity tradeability experiments of Hafter and Carrier (1972), Gilliom and Sorkin (1972), Smith (1976), and Ruotolo *et al.* (1979).

In comparing the predictions of the position-variable model to the results of these interaural discrimination experiments we found the following aspects of the data to be correctly described by the model:

(1) For pure interaural time jnds, the model correctly predicts the general increase of time jnds as the magnitude of the IID increases, and the asymmetry with respect to time delay of time jnds obtained for stimuli presented with interaural amplitude differences. The model also correctly predicts the reversal in direction of the lateralization cue that has been reported by subjects in time-jnd experiments when the ITD is at or near $\pm 1000\,\mu$s.

(2) For pure interaural amplitude jnds, the model correctly predicts a lack of cue reversals, a weaker dependence of amplitude jnds (compared to time jnds) on ITD, and an overall increase of amplitude jnds with increasing IIDs. The quantitative agreement between the predictions of the model and the actual time and amplitude jnds varies considerably from subject to subject.

(3) The model correctly predicts, as do all lateralization models, the general dependence of $NoS\pi$ tone-on-tone masking results for target-to-masker phase angles between 0° and 90°. In addition, the position-variable model correctly decribes many of the trends of the $N\pi So$ coherent-masking results of Yost *et al.* (1974), although again the quantitative agreement of the predictions and data varies from subject to subject. The model also provides a good description of all of the results of Jeffress and McFadden's (1971) lateralization and α-sweep experiments using coherent narrowband targets and maskers, as do all lateralization models.

On the other hand, several aspects of the theoretical predictions are clearly incompatible with the observed data:

(1) The model predicts that interaural time jnds become extremely large for stimuli presented with certain values of ITD. Although these large jnds are observed for a small minority of subjects, the performance of most subjects is significantly better than the predictions for these ITDs.

(2) Observed performance in $NoS\pi$ detection experiments with coherent targets and maskers is substantially better than what is predicted by the model for some values of target-to-masker phase angles between 90° and 150°. (All other lateralization models fail in a similar fashion.)

(3) Subjects in time-intensity tradeability studies can achieve good discrimination performance with two binaural tones for which the dominant subjective positions are identical. Since predictions of the position-variable model are based on the subjective lateral position of a single image, it predicts chance performance with these stimuli.

We note that in all cases when experimental results are in obvious conflict with theoretical predictions, the observed performance is better than predicted. All of these results are problematical not only for the position-variable model, but also for any other model that attempts to relate discrimination performance to the subjective lateral position of a single dominant binaural image.

II. DISCUSSION

In general, the comparisons of predictions and data support the hypotheses that performance in most interaural discrimination experiments is based on changes of lateral position, but additional information may be used in experiments for which performance based on position alone would be poor. We postulate that the subject-to-subject variabiltity in the time-jnd data at large reference delays, and the good performance of some time-jnd subjects relative to the predictions of the position variable model, may indicate that these subjects have learned to make use of other spatial attributes of the perceptual image of the sounds when changes in their primary subjective lateral position are small. The potential utility of additional pereceptual cues in interaural discrimination experiments has previously been suggested by Jeffress and McFadden (1971) in discussions of their detection experiments with coherent maskers, and by Hafter and Carrier (1972) for time-intensity tradeability studies, and it is supported by descriptions of perceptual cues used by subjects in Moss' (1979) time-jnd experiments.

While a number of investigators have suggested that performance in time-intensity studies can be improved by the use of secondary components of the stimulus image, there is a lack of agreement concerning the exact nature of the additional perceptual information. Specifically, Whitworth and Jeffress (1961) and Hafter and Jeffress (1968) have described a "time image" that is almost completely independent of the IID of the stimulus. A different type of secondary image, described by some subjects in the experiments of Ruotolo *et al.* (1979), appears at the ear receiving the signal that is of greater intensity but lagging in time. A third type of secondary image can be perceived in either ear when certain subjects are presented with an equal-intensity pure tone of ITD equal to half the stimulus period, as reported by Sayers (1964) and Yost (1981). In addition to the position of a secondary spatial image, the actual subjective cue (besides lateral position) used in the discrimination experiments considered could be a difference in image diffuseness, shape, or some other difference in quality between the two stimuli to be discriminated. It is not at all obvious that the same type of additional information is used for each of the three classes of results that are not predicted by the position-variable model. These subtleties in the subjective image of binaural sounds may be of concern to those who measure binaural perception in a clinical setting, in that untrained subjects may or may not respond according to these secondary stimulus attributes of the stimuli when changes of lateral position are not available as a cue.

Although it is relatively easy to modify the position-variable model to predict the types of secondary images that have been described to date, we are not attempting to rigorously develop decision variables to describe any of these images at present. We have found the subjective percepts to be extremely complex even for a pure tone, and we have had difficulty separating this complexity into simple variables. It appears that the system is relatively "plastic" and that many different aspects of the stimulus can be isolated by a careful, trained observer and used as a decision variable.

In general, a model based on lateral position (and the position-variable model in particular) can account for many of the salient features of the data. There are other perceptual attributes that are used in some experiments, but these other attributes appear to affect discrimination performance only when the mean lateral position cue is eliminated by careful experimental design. Almost all of the other results in interaural discrimination can be accounted for by a model based on changes of the lateral position of a single image and its variability.

III. CONCLUSIONS

We have compared the performance of the position-variable model of binaural interaction to the results of interaural discrimination experiments using 500-Hz stimuli. We have found that a single position variable appears to be adequate for many discrimination experiments; however, an additional decision variable is required to describe other types of experiments. The model generally provides good predictions for experiments in which subjects report using position as the major cue, while in many of the experimental results that differ from the predictions, great intersubject variability is noted and the task is characterized by subjects as difficult to perform. We believe that lateral position is used as the subjective cue in all experiments considered, and that some additional cues are used for those experiments in which performance on the basis of lateral position alone would be very poor. To the extent that our model accurately characterizes lateral position and its variability, these discrepancies between theoretical predictions and interaural discrimination data would also be seen in the performance of any model in which judgments are assumed to be based solely on the lateral position of a single perceptual image.

ACKNOWLEDGMENTS

This work was supported by the National Institutes of Health (grants 5RO1 NS01344, 5RO1 NS10916, and 5RO1 NS14908). Preparation of the manuscript was partially supported by NIH Training grant 5T32 GMO7477. We also thank C. Trahiotis for helpful comments on many earlier drafts of this manuscript.

[1]See AIP document no. PAPS JASMA-77-753-29 for all 29 pages of the longer paper "Subjective Lateral Position and Interaural Discrimination." Order by PAPS number and journal reference from American Institute of Physics, Physics Auxilliary Publication Service, 335 East 45th Street, New York, NY 10017. The price is $1.50 for each microfiche (98 pages), or $5.00 for photocopies of up to 30 pages with $0.15 for each page over 30 pages. Airmail additional. Make checks payable to the American Institute of Physics.

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