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Dichotic Listening to Melodic Patterns and Its Relationship to Hemispheric Specialization of Function

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Ear advantages in dichotic listening are generally held to reflect greater involvement of the hemisphere contralateral to the preferred ear. Rationales for this view rely on the assumption that, when information arriving at the two ears is treated as a single complex signal, an advantage to a component of this signal based on ear of input will not interact with an advantage based on some other attribute, such as frequency. This assumption is shown, for the case of dichotically presented melodies, to be unjustified. Dichotic tone pairs that are presented in a sequential context are more accurately perceived and localized when the higher tone is to the right and the lower to the left, than when the higher tone is to the left and the lower to the right. This anisotropy can, in principle, give rise to patterns of ear advantage which may tend in either direction, depending on factors such as type of material presented, level of difficulty, task requirement, and category of listener. Since its basis is unknown, ear advantages resulting from this anisotropy cannot be assumed to reflect greater involvement of either hemisphere in processing the information.

CONSIDERABLE interest has developed concerning the involvement of the two sides of the brain in processing music. The view most commonly held is that, whereas speech is processed predominantly in the left, or dominant, hemisphere (in most right-handers), music is processed predominantly in the right, or nondominant hemisphere. Much support for this view comes from findings using the dichotic listening paradigm. This article reviews the proposed rationales for the use of this paradigm in drawing inferences concerning hemispheric specialization of function and describes a perceptual phenomenon that points to a quite different interpretation of dichotic listening results, at least where musical materials are concerned. The possibility is considered that this perceptual phenomenon could be contributing to patterns of ear advantage for speech materials also.

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In the dichotic listening situation, subjects are presented with two different signals simultaneously, one to each ear, and their percepts through the two ears are evaluated in various ways. For example, the subjects might be asked to recall the signals, or to recognize or identify them. If a higher score is obtained for signals presented to the right ear, this is assumed to reflect greater involvement of the left hemisphere in processing these signals. Analogously, if a higher score is obtained for signals presented to the left ear, this is assumed to reflect greater involvement of the right hemisphere. Further, if differences in patterns of ear advantage occur for the same signals, depending on such factors as task requirement, level of difficulty, and category of listener, these are held to reflect differences in patterns of relative involvement of the two hemispheres in processing the information (see Bradshaw & Nettleton, 1981 and Bryden, 1982, for extensive reviews).

The assumption that patterns of ear advantage should be taken to reflect greater involvement of the hemisphere contralateral to the preferred ear is now widely accepted. The most popular rationale for this assumption, which was first proposed by Kimura (1961, 1967), is as follows. Information travels from ear to hemisphere by both contralateral and ipsilateral routes. However, information ascending the contralateral pathways blocks or occludes information ascending the ipsilateral pathways (Rosenzweig, 1961). Thus, for example, information arising from the right ear reaches the left hemisphere directly. However, information arising from the left ear can reach the left hemisphere only by a circuitous route: first to the right hemisphere and then across the corpus callosum to the left hemisphere (see also Milner, Taylor, & Sperry, 1968; Sparks & Geschwind, 1968). Such information is therefore subject to a delay and perhaps also to some degradation, so that right ear information should win out over left ear information in the left hemisphere. Analogously, left ear information should win out over right ear information in the right hemisphere.

A second part of the argument comes from findings of speech deficits resulting from brain damage. In right-handers, such deficits are associated far more often with damage to the left hemisphere than to the right (Hécaen & Albert, 1978; Penfield & Roberts, 1959). It is therefore accepted that, at least at the level of production, speech is predominantly a left hemisphere function. [See also findings from unilateral cortical suppression through the administration of sodium amytal (Milner, Branch, & Rasmussen, 1964; Rossi & Rosadini, 1967]. It is further assumed that speech is predominantly a left hemisphere function at the perceptual level also.

Dichotic listening studies with speech materials have most commonly produced right ear advantages (Studdert-Kennedy & Shankweiler, 1970; Berlin & McNeil, 1976). It is argued that these advantages are based on the two factors just described: first, dominance of the contralateral auditory pathway over the ipsilateral and second, specialization of the left hemisphere for speech. It is further argued by analogy that right ear advantages for other types of material reflect specialization of the left hemisphere in processing such materials also, and that left ear advantages reflect specialization of the right hemisphere instead. In particular, musical materials have frequently given rise to left ear advantages, and this is taken as demonstrating that music is predominantly a right, or nondominant, hemisphere function (Kimura, 1964; Gordon, 1970; Spellacy, 1970; Bartholomeus, 1974; Kallman & Corballis, 1975; Zatorre, 1979). This view is held despite the fact that the neurological literature is equivocal on the point (Benton, 1977; Marin, 1982).

An alternative explanation for patterns of ear advantage has been advanced by Kinsbourne (1970, 1975). He proposed that activity within a given hemisphere results in a biasing of attention to the contralateral side of space. So, for example, verbal processing, which is assumed to be a left hemisphere function, should bias attention to the right side of space. Conversely, certain nonverbal activities that are assumed to be right hemisphere functions should bias attention to the left side. Such attention biasing is held to give rise to patterns of ear advantage through focusing on the preferred ear (see also Morais & Bertelson, 1973, 1975).

Both the above interpretations of patterns of ear advantage rely on an important statistical assumption; namely, that when information arriving at the two ears is considered as a single complex signal, an advantage to a component of this signal based on ear of input will not interact with an advantage based on some other attribute, such as frequency. In other words, it is assumed that no preference exists for one spatial distribution of a complex sound signal over another. If there were such a preference, this could in principle give rise to patterns of ear advantage, which need not at all reflect greater involvement of the hemisphere contralateral to the preferred ear. The findings described in this article show, at least for the case of melodic patterns, that such a preference does indeed exist, and that it can in principle give rise to ear advantages. It is further shown that factors such as task requirement, level of difficulty, and category of listener can produce shifts in direction and degree of ear advantage based on the one perceptual phenomenon.

The effect can best be introduced by way of a visual analogue. In Figure 1 there are two displays, each consisting of a diagonal line flanked by two circles. In display A, the higher circle is to the left and the lower to the right. In display B, the higher circle is to the right and the lower to the left. It will be shown that, when the horizontal dimension is interpreted as azimuth, and the vertical dimension as frequency, processing is better for combinations in which the higher tone is to the right and the lower to the left (as in B) than for those in which the higher tone is to the left and the lower to the right (as in A). It will further be shown that this advantage to "high-right/

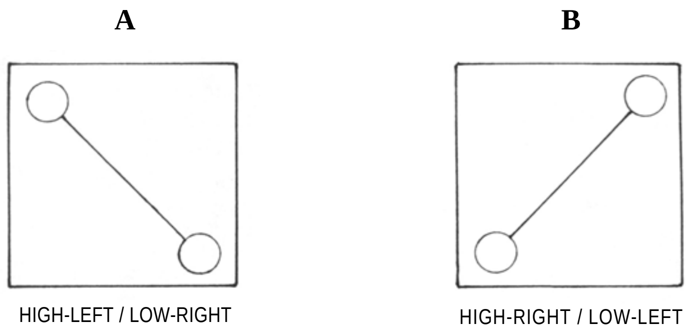

Fig. 1. Visual analogues of the two types of dyad employed in the study. Processing is shown to be better for dyads in which the higher tone is to the right and the lower to the left (as in B) than in which the higher tone is to the left and the lower to the right (as in A).

low-left" combinations is due to a greater compatibility of their component tones rather than to an advantage for either component taken individually.

This study was initially undertaken to elucidate the basis of the scale illusion (Deutsch, 1975, 1982). The stimulus pattern that produces this illusion is shown in the upper portion of Figure 2. This constitutes a major scale, with successive tones alternating from ear to ear. The scale is presented in both ascending and descending form, such that when a tone from the ascending scale is in one ear, a tone from the descending scale is in the other ear.

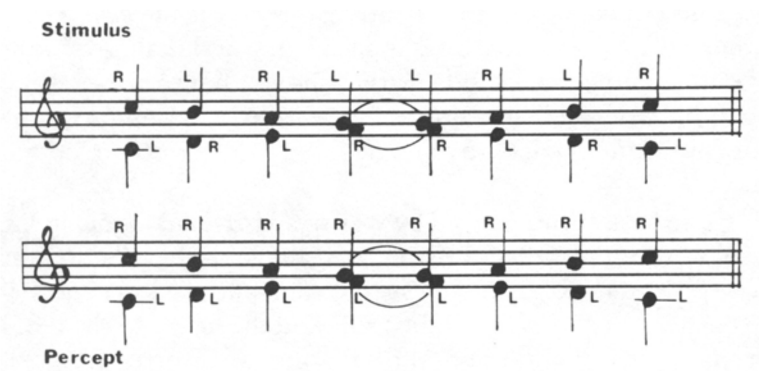

Fig. 2. Configuration producing the scale illusion, and the percept most commonly obtained. The higher tones are heard as on the right and the lower tones as on the left, regardless of how they are presented. Thus, "high-left/low-right" dyads are perceptually reorganized to appear as "high-right/low-left" dyads.

The percept most commonly obtained is shown in the lower portion of Figure 2. This consists of the correct set of pitches, but heard as two separate melodies; a higher one and a lower one, that move in contrary motion. For most right-handers, the higher tones are heard as in the right ear and the lower tones as in the left, and this percept is maintained when the earphones are placed in reverse position.

From an examination of Figure 2 it can be seen that the illusion may be described at a formal level as a correct localization of "high-right/low-left" combinations, combined with an incorrect localization of "high-left/low-right" combinations. For the latter type of combination, the higher tone is perceptually displaced from left to right, and the lower tone from right to left. It can be seen that reversing the earphone positions would not alter this percept, since any "high-left/low-right" combination would still be perceptually reorganized to appear as a "high-right/low-left" combination instead.

Two issues were addressed in this study. First, is the perceptual displacement of high tones to the right and low tones to the left simply a peculiarity of the scale illusion, or does it occur with other melodic patterns also? Second, given the impairment in localization accuracy for "high-left/low-right" combinations, is there also an impairment in perceptual accuracy for tones in these combinations regardless of how they appear localized?

In all experiments, subjects were presented with two simultaneous melodic patterns, one to each ear, and they wrote down in musical notation what they heard. In Experiment 1, the subjects were asked to attend to the pattern delivered to one ear and to ignore the other. By examining patterns of intrusion from the nonattended ear, this method enabled comparison of localization accuracy for tones from "high-right/low-left" combinations with those from "high-left/low-right" combinations. In Experiments 2 and 3, the subjects were asked to listen to the sequences delivered to both ears simultaneously, and to notate all that they could of the entire pattern, without concern for ear of input. This divided attention task enabled comparison of perceptual accuracy for the two types of combination, regardless of how the tones appeared localized.

Experiment 1

Method

Procedure and Stimuli. All subjects were individually tested. On each trial, two sequences of tones were simultaneously presented, one to each ear. The subjects were instructed to attend to the sequence presented to one ear, and then to notate this sequence, ignoring any tones heard in the other ear. An example of a pattern employed is shown in Figure 3. Each ear received a haphazard ordering of the tones F (345 Hz), G (388 Hz), A (435 Hz), B♭ (461 Hz), C (517 Hz), and D (581 Hz), and this was preceded by F (345 Hz), which served both as an anchor tone and also as a warning that the trial was about to begin. The sequence there-

Fig. 3. Stimulus pattern such as employed in Experiments 1 and 2.

fore sounded as consisting of some ordering of the first six notes of the F major scale, preceded by the tonic. Taking the entire set of patterns, there were equal numbers of dyads in which the higher tone was to the right and the lower tone to the left ("high-right/low-left" dyads) and in which the higher tone was to the left and the lower tone to the right ("high-left/low-right" dyads).

All tones within a sequence were 500 msec in duration, and they followed each other without pause. The anchor tone was 1 sec in duration, and was followed by a 2-sec pause. Each sequence was followed by a 30-sec pause, during which the subject made his or her response.

The experiment began with a warm-up period during which the subject listened to and notated three practice patterns, with instructions to attend only to the sequence presented to the right ear or to the left. Following this, 20 test patterns were presented, with the same instructions. There followed a rest period of 5 min. The procedure was then repeated, except that the subject now focused attention on the sequence presented to the other ear. Half of the subjects were instructed to attend to the right ear during the first part of the experiment, and to the left ear during the second part. For the remaining subjects, this order was reversed. The position of the earphones was counterbalanced across subjects for each order of ear focusing.

Apparatus. Tones were generated as sine waves by two Wavetek function generators (Model No. 155) controlled by a PDP11/23 computer and were recorded on tape. The tape was played to subjects on a Revox tape recorder through Grason-Stadler TDH-49 earphones, calibrated, and matched.

Subjects. Twelve paid subjects with normal hearing were employed in the experiment. All had had at least 10 years of musical training. Nine of the subjects were graduate students in the Music Department of the University of California at San Diego; the other three were nonstudents. All subjects were right-handed, as determined by the short form of the Edinburgh Handedness Inventory (Oldfield, 1971).

Results

The results of the experiment are shown in Figures 4-7. Figure 4 displays the percentages of tones that were correctly notated (i.e., in the correct serial positions) when they came from the earphone to which attention was directed. Thus HL (high-left) and LL (low-left) refer to correct notations when the subjects were attending to their left ears, and HR (high-right) and LR (low-right) refer to correct notations when the subjects were attending to their right ears. It can be seen that, although overall performance levels through the two ears were very similar, there were considerable ear differ-

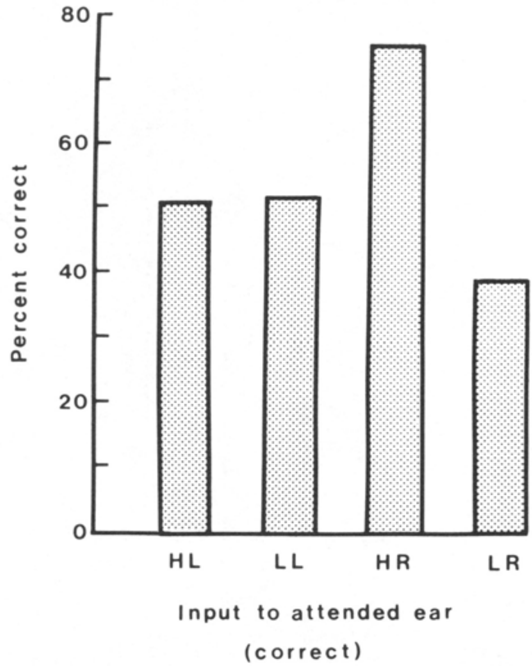

Fig. 4. Percentages of tones that were correctly notated when these came from the earphone to which attention was directed. HL = high-left, LL = low-left, HR = high-right, LR = low-right. (Experiment 1).

ences in performance on the higher relative to the lower tones. Where the right ear was concerned, substantially more higher tones were correctly notated than were lower tones. However, where the left ear was concerned, virtually the same numbers of higher and lower tones were correctly notated, with a marginal advantage to the lower tones.

A three-way analysis of variance was performed, with ear of input (left or right) and position in dyad (higher or lower) as fixed factors, and subjects as a random factor. A marginal effect of ear of input was obtained, with an advantage to the right ear ($F(1, 11) = 6.197$, $p < .05$). A highly significant effect of position in dyad was obtained, with an advantage to the higher tones ($F(1, 11) = 13.909$, $p < .01$). Most importantly, however, the interaction between ear of input and position in dyad was highly significant ($F(1, 11) = 22.493$, $p < .001$), reflecting the difference in the proportions of higher tones to lower tones that were correctly notated through the left and right ears. Comparing the higher tones alone, significantly more of those presented to the right ear were correctly notated than those presented to the left ear (HR vs. HL, $F(1, 11) = 26.768$, $p < .001$). However, compar-

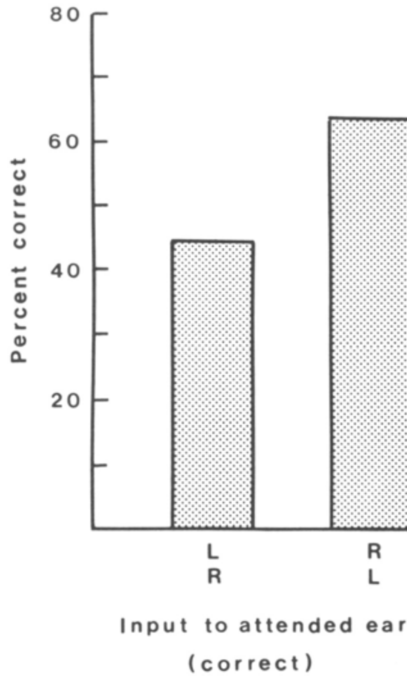

Fig. 5. Percentages of tones that were correctly notated, classified by whether they were from "high-left/low-right" dyads ($^{L}_{R}$), or from "high-right/low-left" dyads ($^{R}_{L}$), taking tones which came from the earphone to which attention was directed. (Experiment 1).

ing the lower tones alone, significantly more of those presented to the left ear were correctly notated than those presented to the right ear (LR vs. LL, $F(1, 11) = 8.231$, $p < .02$).

This interaction is clarified in Figure 5, which displays the same data, classified by whether the tones came from "high-right/low-left" dyads, or from "high-left/low-right" dyads. It can be seen that there was a substantial advantage to the former type of dyad over the latter.

Figure 6 shows the percentages of tones that were correctly notated when these were intrusions (i.e., they came from the earphone that the subject had been instructed to ignore). Thus HL (high-left) and LL (low-left) refer to intrusions when the subjects were attending to their right ears, and HR (high-right) and LR (low-right) refer to intrusions when the subjects were attending to their left ears. It can be seen that, again, although overall performance levels through the two ears were very similar, the proportions of higher to lower intrusions were quite different. More higher than lower tones intruded from the left to the right. However, more lower than higher tones intruded from the right to the left.

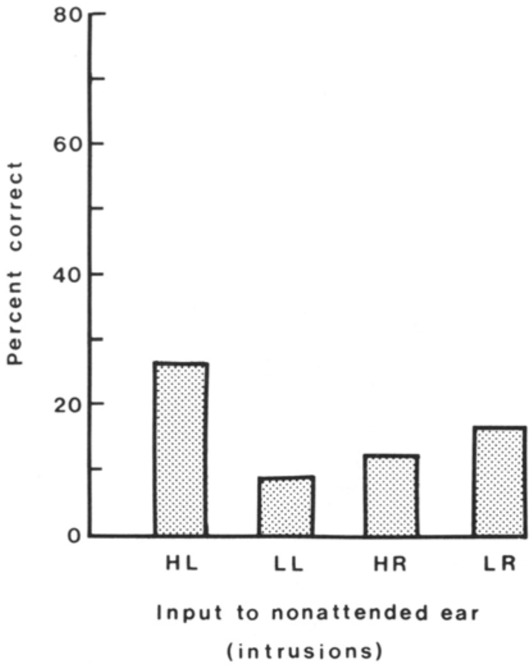

Fig. 6. Percentages of tones that were correctly notated, when these came from the earphone that the subject had been instructed to-ignore. HL = high-left, LL = low-left, HR = high-right, LR = low-right. (Experiment 1).

A three-way analysis of variance was performed, with ear of input and position in dyad as fixed factors and subjects as a random factor. There was no overall effect of ear of input ($F < 1$). The effect of position in dyad was also nonsignificant ($F(1, 11) = 4.672$, $p > .05$). However, the interaction between ear of input and position in dyad was highly significant ($F(1, 11) = 9.780$, $p < .01$), reflecting the difference in the proportions of higher to lower intrusions from the left and right ears. Considering the higher tones alone, significantly more intrusions occurred from left to right (HR vs. HL, $F(1, 11) = 6.064$, $p < .05$). However, considering the lower tones alone, significantly more intrusions occurred from right to left (LR vs. LL, $F(1, 11) = 5.672$, $p < .05$).

This interaction is clarified in Figure 7, which displays the same data classified by whether the tones came from "high-right/low-left" dyads or from "high-left/low-right" dyads. It can be seen that substantially more intrusions occurred from the latter type of dyad than from the former.

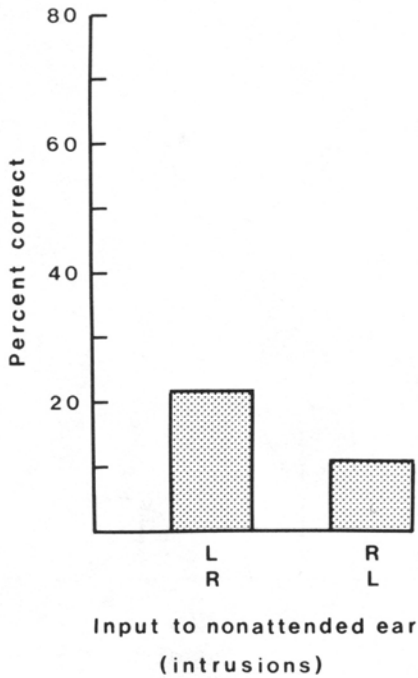

Fig. 7. Percentages of tones that were correctly notated, classified by whether they were from "high-left/low-right" dyads ($\frac{L}{R}$) or from "high-right/low-left" dyads ($\frac{R}{L}$), taking tones which came from the earphone that the subject had been instructed to ignore. (Experiment 1).

Discussion

Three findings emerged from this experiment. First, higher tones were more accurately notated than were lower tones. Second, tones from "high-right/low-left" dyads were more accurately notated than those from "high-left/low-right" dyads. Third, more tones from "high-left/low-right" dyads than from "high-right/low-left" dyads were notated as intrusions.

Concerning the intrusions, since the subjects were asked to notate only the tones coming from one earphone and to ignore the others, we can conclude that the intruding tones were heard as though coming from the earphone to which attention was directed.[1] This pattern therefore reflects an instability of localization for "high-left/low-right" dyads: There was a tendency to localize higher tones to the right and lower tones to the left, regard-

1. This was confirmed by introspective reports: subjects remarked that the right earphone appeared to be producing mostly higher tones and the left earphone mostly lower tones.

less of how they were presented. (This may also explain the larger number of correct notations from "high-right/low-left" dyads, since the tones from these dyads would, on this line of reasoning, be more accurately localized.) This experiment therefore shows that the perceptual tendency to displace higher tones to the right and lower tones to the left is not restricted to the scale illusion, but occurs with haphazard patterns also.

We now consider the implications of these findings for the interpretation of patterns of ear advantage for melodic materials. In probing for such ear advantages, the following paradigm has generally been employed (following Kimura, 1964). The subject is presented with two melodies simultaneously, one to each ear. This dichotic presentation is followed by four binaural melodies in succession. Two of these are identical to the melodies that had been presented dichotically and two are different, and the subject's task is to choose which two he or she had heard. If significantly more melodies are identified from the right ear, this is held to reflect superiority of the left or dominant hemisphere in performing the task. Analogously, if significantly more melodies are identified from the left ear, this is held to reflect superiority of the right or nondominant hemisphere instead.

Such conclusions presuppose that dichotically presented melodies are heard either veridically or as degraded in some nonspecific way; however, the present findings show instead that the incoming melodies are distorted in a systematic fashion. Consider, for example, the stimulus and percept represented in Figure 2. The melodies that are presented to each ear are clearly very different from those that are *perceived as though* presented to each ear. So if this pattern were employed in the Kimura paradigm, the subject's judgments would have to be based, not on genuine recognition of the melodies that had been presented, because they had not been perceived in the first place, but rather on judgments of similarity between the illusory melodies that had been perceived and the melodies that were later presented.

This leads us to consider what factors might influence such similarity judgments. Statistically, in the dichotic situation, the melody perceived as though in the right ear contains more extraneous high tones than the melody perceived as though in the left ear. Further, the melody perceived as though in the left ear contains more extraneous low tones than the melody perceived as though in the right ear. Suppose that a melody is made more dissimilar by the inclusion of extraneous high tones rather than low tones: this should lead to a left ear advantage in this paradigm. Suppose that a melody is instead made more dissimilar by the inclusion of extraneous low tones: this should then lead to a right ear advantage. The relative importance of extraneous high tones compared with low tones is likely to vary, depending on the precise melodic configuration presented. In either event, however, ear advantages due to such factors would not be based on superior processing by the hemisphere contralateral to the ear associated with the larger number of identifications, but would rather reflect a bias of perceptual reorganization.

Experiment 2

Experiment 1 examined performance under focused attention conditions and was addressed to the question of localization accuracy for "high-right/ low-left" dyads as compared with "high-left/low-right" dyads. The superior performance found on the former type of dyad over the latter raises the question of how well tones from these two types of dyad are perceived when localization accuracy is not at issue. This question was examined in Experiment 2. Subjects listened to dichotic patterns that were designed as in the first experiment. However, instead of focusing attention on one ear and ignoring the other, they were asked to notate the entire pattern without regard for ear of input.

Method

Procedure and Stimuli. The stimulus parameters were as in Experiment 1. All subjects were individually tested. They were asked to listen to the dichotic pattern presented on each trial and then to notate the entire pattern without regard for ear of input. Following a warm-up period during which the subject listened to and notated three practice patterns, 20 test patterns were presented. The placement of earphones was counterbalanced subjects.

Apparatus. This was the same as for Experiment 1.

Subjects. Ten paid subjects with normal hearing participated in the experiment, selected on the same criteria as for Experiment 1. Six subjects were graduate students in the Music Department at the University of California at San Diego, two were undergraduates, and two were nonstudents.

Results

Figure 8A shows the percentages of tones that were correctly notated (i.e., in the correct serial positions) classified as high-left (HL), low-left (LL), high-right (HR), and low-right (LR). A three-way analysis of variance was performed, with ear of input (left or right) and position of dyad (higher or lower) as fixed factors, and subjects as a random factor. The effect of ear of input was nonsignificant ($F(1, 9) = 2.356$, $p > .05$). A significant effect of position in dyad was obtained, with superior performance on the higher tones ($F(1, 9) = 8.311$, $p < .02$). Most importantly, there was a highly significant interaction between ear of input and position in dyad ($F(1, 9) = 13.739$, $p = .005$), reflecting the difference in the proportions of correct notations for the higher and lower tones presented to the left and right ears.

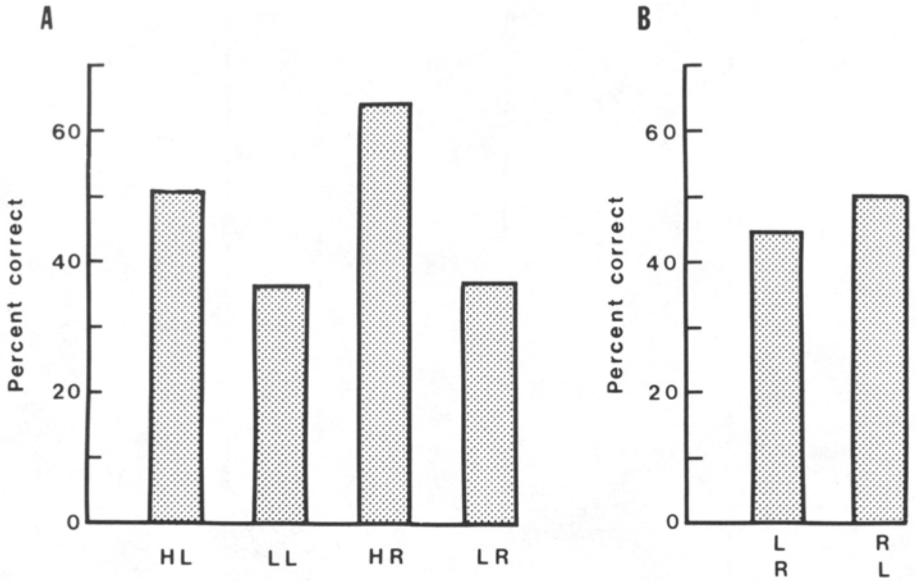

Fig. 8. (A) Percentages of tones that were correctly notated. HL = high-left, LL = low-left, HR = high-right, LR = low-right. (B) Same data as shown in (A), classified by whether the tones came from "high-left/low-right" dyads ($\genfrac{}{}{0pt}{}{L}{R}$) or from "high-right/low-left" dyads ($\genfrac{}{}{0pt}{}{R}{L}$). (Experiment 2).

The basis for this interaction becomes clear when the tones are considered as coming either from "high-right/low-left" dyads or from "high-left/low-right" dyads. As shown in Figure 8B, more tones from the former type of dyad were correctly notated than from the latter. More specifically, significantly more HR than HL tones were correctly notated ($F(1, 9) = 8.089$, $p < .02$). However, the numbers of correct notations of LR and LL tones did not differ significantly ($F < 1$). Since localization judgments were not required in this experiment, we can conclude that the advantage to "high-right/low-left" dyads extends to perception of their component tones, regardless of how they appear localized.

The question then arises of whether the enhanced performance on "high-right/low-left" dyads was due to superior processing of the tones from these dyads taken independently, or rather to a greater compatibility of these tones. As shown in Figure 9, the results support the latter hypothesis. There were significantly more "high-right/low-left" dyads from which both tones were notated correctly ($F(1, 9) = 5.582$, $p < .05$). There were also significantly fewer "high-right/low-left" dyads from which neither tone was notated correctly ($F(1, 9) = 7.156$, $p = .025$). However, the numbers of dyads from which only one tone was notated correctly did not differ significantly ($F < 1$).

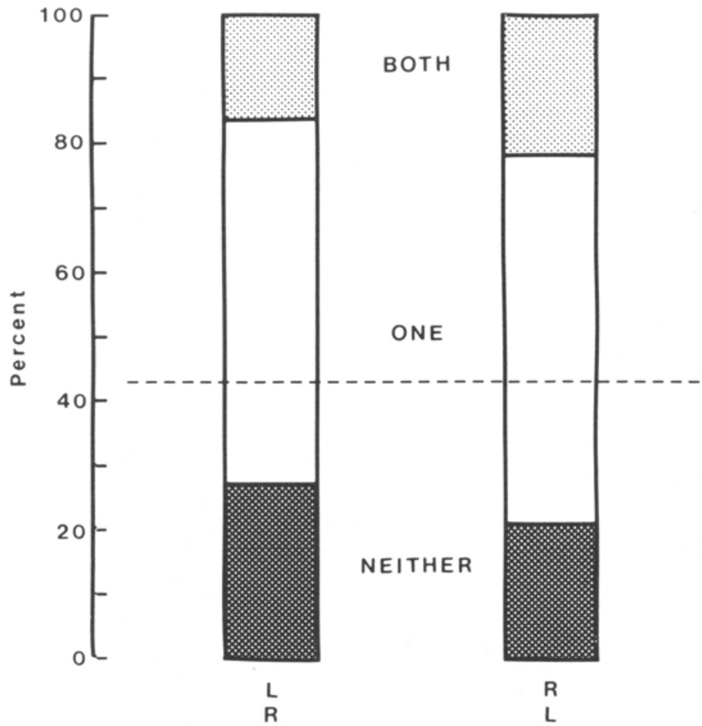

Fig. 9. Percentages of dyads from which both tones were correctly notated, from which only one tone was correctly notated, and from which neither tone was correctly notated, shown separately for "high-left/low-right" dyads ($\frac{L}{R}$), and for "high-right/low-left" dyads ($\frac{R}{L}$). (Experiment 2).

From this pattern of results it would appear that the interaction between position in dyad and ear of input found for individual tones could have been due solely to performance on those dyads from which both tones were notated correctly. To examine this possibility, the percentages of tones that were correctly notated were again tabulated; but now separately for dyads from which both tones were notated correctly and for dyads from which only one tone was notated correctly. These are displayed in Figures 10A and B. In the former case, the percentages of correct notations of "high-right" and "low-left" tones were necessarily identical, as were those of "high-left" and "low-right" tones. For the latter case, a three-way analysis of variance was performed, with position in dyad and ear of input as fixed factors and subjects as a random factor. The effect of ear of input was non-significant ($F(1, 9) = 2.356$, $p > .05$). The effect of position in dyad was significant, with an advantage to the higher tones ($F(1, 9) = 8.311$, $p < .02$). But most importantly, in contrast to the combined analysis, there was now no interaction between position in dyad and ear of input ($F < 1$).

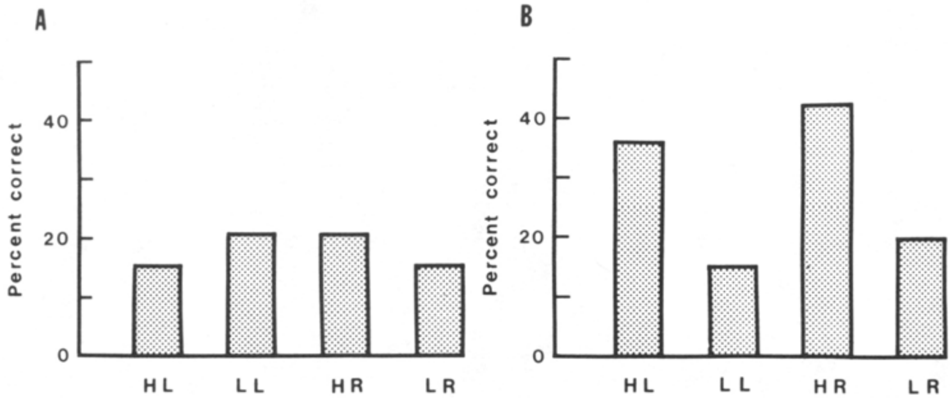

Fig. 10. Percentages of tones that were correctly notated, from dyads from which both tones were correctly notated (A), and from dyads from which only one tone was correctly notated (B). HL = high-left, LL = low-left, HR = high-right, LR = low-right. (Experiment 2).

Thus the interaction found in the combined results was indeed due to the presence of a larger number of "high-right/low-left" dyads from which both tones were notated correctly.

Discussion

In the dichotic listening paradigm, ear advantages can only be obtained when one but not both of the simultaneous signals are responded to correctly. Let us then consider the results of a hypothetical experiment in which the overall performance is higher than the present one, and the horizontal dotted line on Figure 9 represents a floor to the error rate. Let us further assume that, as in the present experiment, performance on the higher tones is superior to performance on the lower tones. Because a larger number of "high-right/low-left" dyads are in the "Both" category, and so are pulled out of the pool of dyads from which ear advantages may be obtained, the remaining pool contains an inflated number of "high-left/low-right" dyads. Given superior performance on the higher tones, an artifactual left ear advantage should emerge. If, however, the task were instead such that superior performance was obtained on the lower tones, an artifactual right ear advantage should emerge.

Let us now consider the results of a hypothetical experiment in which the overall performance level is lower than the present one, and the horizontal dotted line represents a ceiling to the error rate. Because a larger number of "high-left/low-right" dyads are in the "Neither" category, and so are pulled

Fig. 11. Stimulus patterns such as employed in the different conditions of Experiment 3. (A) All dyads were of the "high-right/low-left" type. (B) All dyads were of the "high-left/low-right" type. (C) Dyads of the "high-right/low-left" type alternated with dyads of the "high-left/low-right" type.

out of the pool of dyads from which ear advantages can be obtained, there remains an inflated number of "high-right/low-left" dyads in this pool. Given superior performance on the higher tones, an artifactual right ear advantage should emerge. Further, given superior performance on the lower tones, an artifactual left ear advantage should emerge instead.

We can thus see that, because of the single anisotropy shown here, artifactual patterns of ear advantage may be produced, which can tend in either direction, depending on such factors as overall error rate and relative prominence of higher or lower components of the frequency spectrum. Such artifactual ear advantages would occur despite counterbalancing of the position of the earphones. The implications of this conclusion will be discussed at the end of this article.

Experiment 3

In Experiment 2, comparison was made between ease of processing of "high-right/low-left" dyads and of "high-left/low-right" dyads, when these were presented in haphazard order. Experiment 3 examined this issue when the two types of dyad were presented in various systematic orders instead. Three types of pattern were employed, and examples of these are shown in Figure 11. In the first, the higher tones of all dyads were presented to the right ear and the lower to the left. In the second, the higher tones of all dyads were presented to the left ear and the lower to the right. In the third, dyads of the "high-right/low-left" type alternated with dyads of the "high-left/ low-right" type.

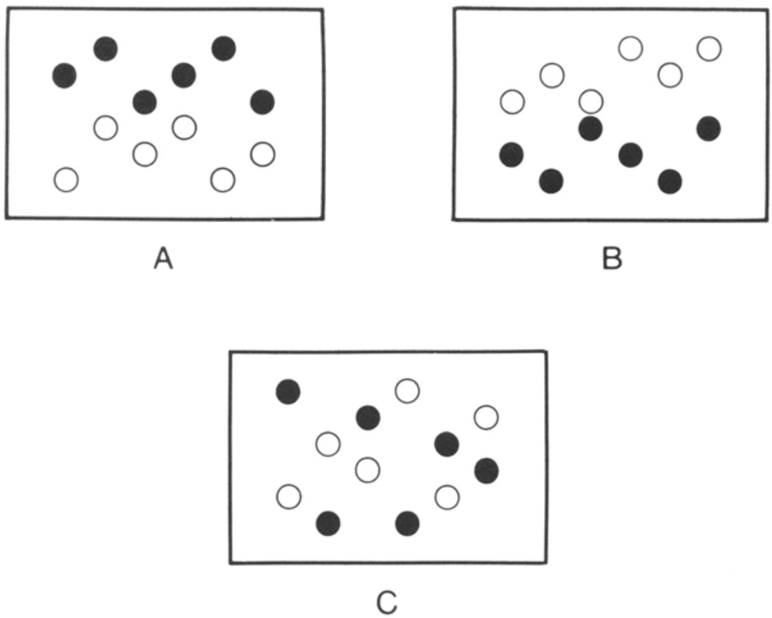

Fig. 12. Visual analogues of the three types of pattern employed in Experiment 3. Closed circles represent tones to the right, and open circles represent tones to the left.

Now, in the first two types of pattern, the higher and lower tones of all dyads were each consistently associated with a given ear. But in the third type of pattern, tones associated with a given ear alternated between the higher and the lower positions in the dyad. So for this third type, grouping by ear of input would be expected to conflict with grouping by position in dyad. A visual analogue of this proposed effect is shown in Figure 12, in which the closed circles represent tones to the right and the open circles represent tones to the left. In displays A and B, analogous to the first two types of pattern, two groupings are readily perceived; one corresponding to the filled circles and the other to the unfilled circles. However, in display C, analogous to the "alternating" type of pattern, two groupings are less readily perceived. It was therefore hypothesized that, because of this impaired ability to form perceptual groupings, performance on the "alternating" type of pattern should suffer relative to the others.

Method

Procedure and Stimuli. The stimulus parameters were as in Experiments 1 and 2, except that the orderings of the two types of dyad within a pattern were varied. In the first type of pattern, all dyads were of the "high-right/low-left" type. In the second, all dyads were of the "high-left/low-right" type. In the third, dyads of the "high-right/low-left" type alternated with dyads of the "high-left/low-right" type. Eight examples of each type of pattern were generated, making 24 patterns in all. The order of presentation of the three types of pattern was counterbalanced across subjects, as was positioning of the earphones. The subjects were asked, as in Experiment 2, to listen to the entire pattern presented on each trial, and then to notate the pattern without regard for ear of input. The 24 test patterns were preceded by a warm-up period during which three practice patterns were presented.

Apparatus. This was the same as in Experiment 1.

Subjects. Twelve paid subjects with normal hearing participated in the experiment, selected on the same criteria as for Experiments 1 and 2. Six were graduate students in the Music Department at the University of California at San Diego, two were undergraduates, and four were nonstudents.

Results

Table 1 shows the percentages of tones that were correctly notated (i.e., in the correct serial positions) for the three types of pattern. Best performance was obtained for "high-right/low-left" patterns, followed by "high-left/low-right" patterns, with poorest performance on "alternating" patterns. A two-way analysis of variance was performed, with type of pattern as a fixed factor, and subjects as a random factor. The effect of type of pattern was highly significant ($F(2, 22) = 11.878$, $p < .001$). Further analyses showed that the difference between "high-right/low-left" patterns and "alternating" patterns was highly significant ($F(1, 11) = 16.656$, $p < .01$) as was the difference between "high-right/low-left" and "high-left/low-right" patterns ($F(1, 11) = 14.080$, $p < .01$). However, the difference between "high-left/low-right" and "alternating" patterns was not significant ($F(1, 11) = 2.555$, $p > .05$).[2]

Further analyses confirmed the findings of Experiment 2, both for patterns consisting entirely of "high-right/low-left" dyads or of "high-left/low-

TABLE 1
Tones Correctly Notated for the Three Types of Pattern in Experiment 3

A. All dyads of high-right/low-left type	46.5%
B. All dyads of high-left/low-right type	42.3%
C. High-right/low-left dyads alternate with high-left/low-right dyads	40.0%

2. This lack of significance is as expected, since half of the dyads in the "alternating" patterns were of the "high-right/low-left" type, which should have served to counteract the impairment in performance due to a conflict between grouping by ear of input and by position in dyad.

right" dyads and also for patterns in which the two types of dyad were presented in alternation.

Figure 13A shows the percentages of tones that were correctly notated, for patterns of the "high-right/low-left" type and of the "high-left/low-right" type. A three-way analysis of variance was performed, with ear of input and position in dyad as fixed factors and subjects as a random factor. There was no effect of ear of input ($F < 1$). The effect of position in dyad was highly significant ($F(1, 11) = 18.648$, $p = .001$). The interaction between ear of input and position in dyad was also highly significant ($F(1, 11) = 14.080$, $p < .005$). Figure 13B clarifies this interaction, by displaying the same data, classified by whether the tones came from "high-right/low-left" dyads or from "high-left/low-right" dyads. It can be seen that more tones from the former type of dyad were correctly notated than from the latter. This pattern of results is very similar to that obtained in Experiment 2, in which the two types of dyad were presented in haphazard order.

The question may again be raised of whether the enhanced performance on "high-right/low-left" dyads was due to superior processing of tones from these dyads taken independently or rather to a greater compatibility of these tones. As shown in Figure 14, there were more "high-right/low-

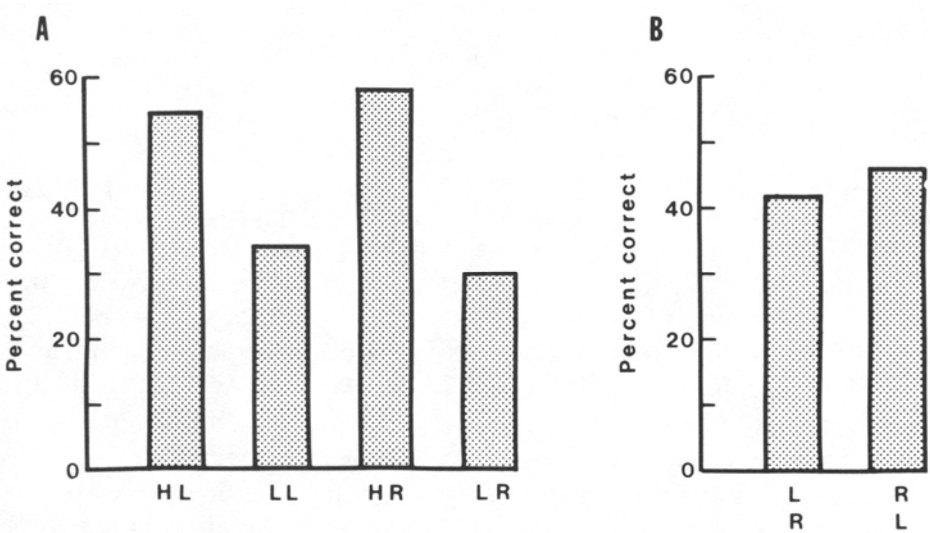

Fig. 13. (A) Percentages of tones that were correctly notated, taking patterns in which all dyads were either of the “high-right/low-left” type or of the “high-left/low-right” type. HL = high-left, LL = low-left, HR = high-right, LR = low-right. (B) Same data as shown in (A), classified by whether the tones came from “high-left/low-right” dyads ($\genfrac{}{}{0pt}{}{L}{R}$) or from “high-right/low-left” dyads ($\genfrac{}{}{0pt}{}{R}{L}$). (Experiment 3).

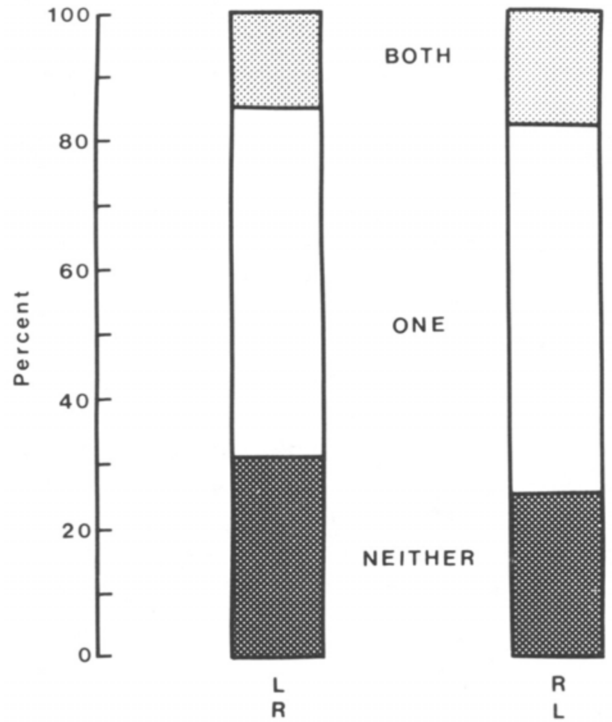

Fig. 14. Percentages of dyads from which both tones were notated correctly, from which only one tone was notated correctly, and from which neither tone was notated correctly, shown separately for "high-left/low-right" dyads (L over R) and for "high-right/low-left" dyads (R over L), taking patterns in which all dyads were either of the "high-right/low-left" type or of the "high-left/low-right" type. (Experiment 3).

left" dyads from which both tones were notated correctly; this effect was highly significant ($F(1, 11) = 9.514$, $p = .01$). There were fewer "high-right/low-left" dyads from which neither tone was notated correctly; this effect was also highly significant ($F(1, 11) = 10.129$, $.p <.01$). The numbers of dyads from which only one tone was notated correctly did not, however, differ significantly ($F(1, 11) = 2.772$, $p <.05$). We can conclude, therefore, that the enhanced performance on "high-right/low-left" dyads was indeed due to a greater compatibility of their component tones.

We may then enquire whether, as in Experiment 2, the interaction between ear of input and position in dyad found in the combined results was due to performance on those dyads from which both tones were notated correctly. To determine this, the percentages of tones that were correctly notated were tabulated separately for dyads from which both tones were notated correctly and for those from which only one tone was notated

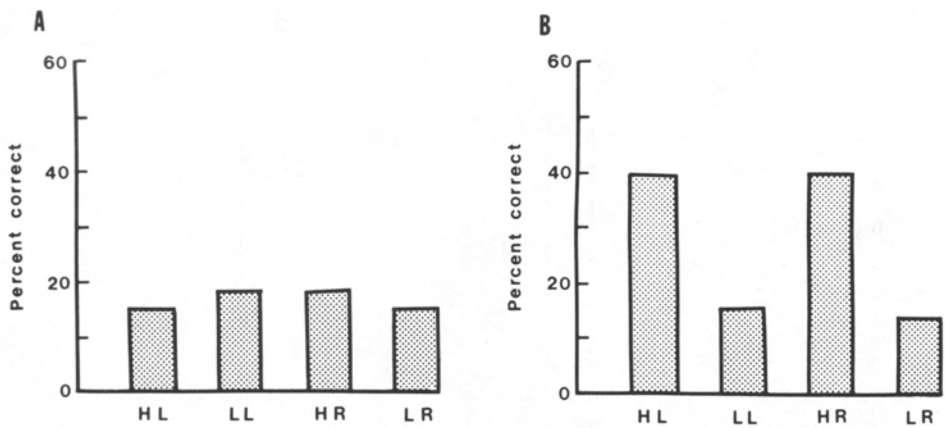

Fig. 15. Percentages of tones that were correctly notated, from dyads from which only one tone was notated correctly (A) and from which both tones were notated correctly (B), taking patterns in which all dyads were either of the "high-right/low-left" type or of the "high-left/low-right" type. HL = high left, LL = low-left, HR = high-right, LR = low-right. (Experiment 3).

correctly. These are shown in Figure 15. For the latter case,[3] a three-way analysis of variance was performed, with ear of input and position in dyad as fixed factors and subjects as a random factor. The effect of ear of input was nonsignificant ($F < 1$). The effect of position in dyad was highly significant ($F(1, 11) = 18.648$, $p < .001$). However, the interaction between these two factors was not significant ($F(1, 11) = 2.772$, $p > .05$). Thus, as in Experiment 2, the interaction found in the combined results was due to the presence of a larger number of "high-right/low-left" dyads from which both tones were notated correctly.

Finally, the same analyses were performed on the results from patterns in which dyads of the "high-right/low-left" type alternated with dyads of the "high-left/low-right" type. Figure 16A shows the percentages of tones that were correctly notated for this "alternating" type of pattern. A three-way analysis of variance was performed, with ear of input and position in dyad as fixed factors, and subjects as a random factor. There was no effect of ear of input ($F < 1$). The effect of position in dyad was highly significant ($F(1, 11) = 9.974$, $p < .01$). Further, the interaction between ear of input and position in dyad was significant ($F(1, 11) = 7.408$, $p = .02$). Figure 16B clarifies this interaction, by displaying the same data, classified by whether the tones came from "high-right/low-left" dyads, or from "high-

3. As in Experiment 2, for the case of dyads from which both tones were notated correctly, the numbers of correct notations of "high-right" and "low-left" tones were necessarily identical, as were those of "high-left" and "low-right" tones.

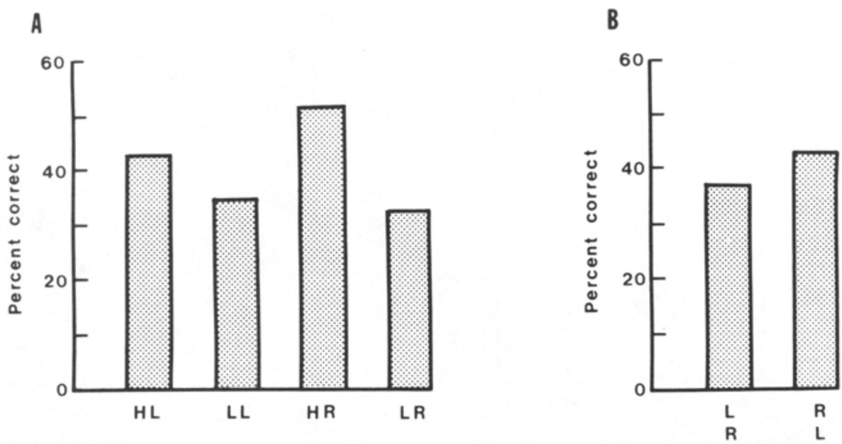

Fig. 16. (A) Percentages of tones that were correctly notated, taking patterns in which dyads of the “high-right/low-left” type alternated with dyads of the “high-left/low-right” type. HL = high-left, LL = low-left, HR = high-right, LR = low-right. (B) Same data as shown in (A), classified by whether the tones came from “high-left/low-right” dyads ($\binom{L}{R}$), or from “high-right/low-left” dyads ($\binom{R}{L}$). (Experiment 3).

left/low-right" dyads. It can be seen that more tones from the former type of dyad were correctly notated than from the latter. This pattern of results is again very similar to that obtained in Experiment 2.

Again raising the question of whether the enhanced performance on "high-right/low-left" dyads was due to a greater compatibility of their component tones, the percentages of dyads were plotted of which both tones were notated correctly, of which only one tone was notated correctly, and of which neither tone was notated correctly. These are shown in Figure 17.

There were more "high-right/low-left" dyads of which both tones were notated correctly, although this effect did not reach statistical significance ($F(1, 11) = 3.617$, $p > .05$). There were significantly fewer "high-right/ low-left" dyads from which neither tone was notated correctly ($F(1, 11) = 6.061$, $p < .05$). The difference in the numbers of "high-right/low-left" and "high-left/low-right" dyads from which only one tone was notated correctly was insignificant ($F < 1$). This pattern is therefore very similar to that found for haphazard sequences in Experiment 2 and also for sequences in which all the higher tones were presented to one ear and all the lower tones to the other ear, in the present experiment.

Finally, we may enquire for the "alternating" patterns whether the interaction found in the combined results between ear of input and position in dyad was due to performance on those dyads from which both tones were notated correctly. To determine this, the percentages of tones that were correctly notated were tabulated separately for dyads from which both tones

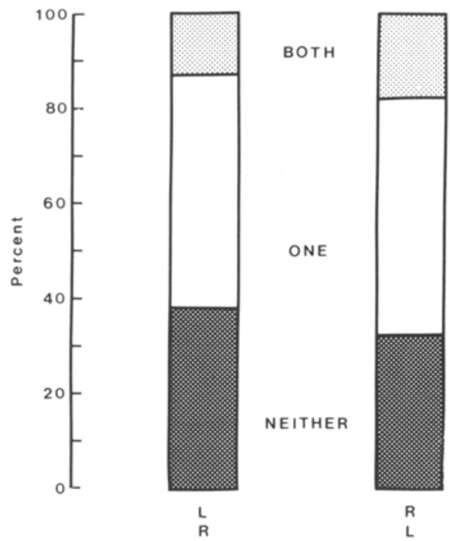

Fig. 17. Percentages of dyads from which both tones were notated correctly, from which only one tone was notated correctly, and from which neither tone was notated correctly, shown separately for "high-left/low right" dyads $\binom{L}{R}$ and for "high-right/low-left" dyads $\binom{R}{L}$, taking patterns in which "high-right/low-left" dyads alternated with "high-left/low-right" dyads. (Experiment 3).

were notated correctly, and from which only one tone was notated correctly. These are shown in Figure 18. Taking dyads from which only one tone was notated correctly, a three-way analysis of variance was performed, with ear of input and position in dyad as fixed factors and subjects as a random factor. There was no effect of ear of input ($F < 1$). The effect of position in dyad was significant ($F(1, 11) = 9.974$, $p < .01$). There was, however, no interaction between ear of input and position in dyad ($F < 1$). Thus, again, the interaction found in the combined results was due to the larger number of "high-right/low-left" dyads from which both tones were notated correctly.

In summary, the results of this experiment extend those of Experiment 2 by showing that the same perceptual anisotropy occurs in patterns in which all the higher tones are presented to one ear and all the lower tones to the other, and also in patterns in which the higher and lower tones are presented in alternation to the two ears. They also show that performance lev-

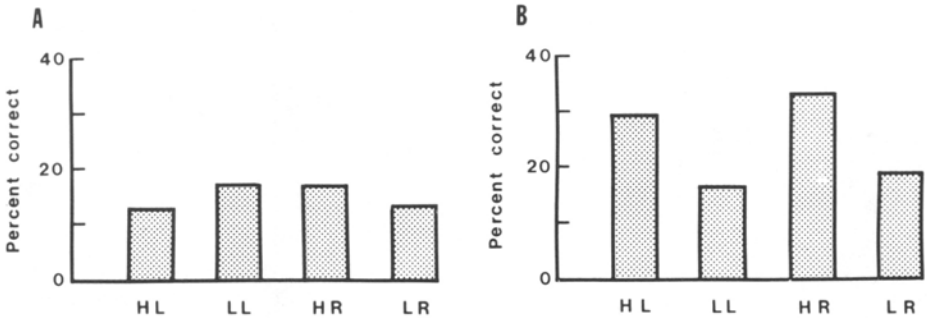

Fig. 18. Percentages of tones that were correctly notated, from dyads in which both tones were correctly notated (A), and from dyads from which only one tone was correctly notated (B), taking patterns in which "high-right/low-left" dyads alternated with "high-left/low-right" dyads HL = high-left, LL = low-left, HR = high-right, LR = low-right. (Experiment 3).

els are higher for patterns in which the higher and lower tones are each consistently associated with a particular ear compared with patterns in which a conflict is induced between grouping by frequency range and by ear of input.

General Discussion

The present set of findings demonstrates a left—right anisotropy in the perception of tone combinations which has two major manifestations. First, there is a tendency to perceive higher tones as on the right and lower tones as on the left, regardless of how they are presented. As a result, combinations of the "high-right/low-left" type tend to be accurately localized, and combinations of the "high-left/low-right" type tend to be mislocalized. Second, there is a tendency for enhanced perceptual accuracy for tones presented in "high-right/low-left" combinations compared with "high-left/low-right" combinations, regardless of how these tones appear localized.

These findings have several implications. The most direct ones concern patterns of ear advantage for dichotically presented melodies. Artifactual ear advantages may result from the anisotropy in two ways: first from the mislocalization effects, and second from the creation of an unbalanced pool of stimuli from which ear advantages can be obtained. In either event, ear advantages resulting from this anisotropy would occur despite counterbalancing of the earphones. Since the basis of the anisotropy is unknown, resultant ear advantages cannot be assumed to reflect greater involvement of either hemisphere in processing the information.

In this context, it is of interest to reconsider the study of Kallman and Corballis (1975), which is frequently cited as demonstrating right hemisphere superiority in processing musical sounds. Tape recordings were made of a note A (440 Hz) played on a bassoon, viola, piano, and cello. The cello note was designated as the target, and subjects listened to dichotic pairs of these notes and responded whenever they heard the target sound. Reaction times were faster initially when the target was presented to the left ear than to the right. This was assumed to reflect greater involvement of the right hemisphere in processing such sounds. However, given the present findings, we might hypothesize that the left ear advantage was instead due to the subjects' focusing on the lower portions of the frequency spectrum in making their judgments. Indeed, the left ear advantage occurred only in the first block of trials, and not later in the experiment. This could have been due to the subjects shifting their focusing strategies away from the lower spectral components as the experiment progressed.

Although the implications of the present findings can most directly be applied to tonal materials, the anisotropy may also contribute to patterns of ear advantage for speech materials. The hypothesis that speech gives rise to right ear advantages because it is processed in the left hemisphere leaves various findings unexplained. For example, some speech sounds produce no ear advantage (Shankweiler & Studdert-Kennedy, 1967; Darwin, 1971) and some produce a left ear advantage (Cutting, 1974). Even when a right ear advantage is obtained, it differs in degree depending on the type of consonant and consonant—vowel pairing presented (Allard & Scott, 1975; Darwin, 1971; Haggard, 1971; Repp, 1977, 1978; Hayden, Kirstein, & Singh, 1979; Bryden, 1982; Lauter, 1983). The bases for such differences have not been clarified. The present anisotropy provides a potential explanation, since the identification of different speech sounds in the dichotic situation could involve differential focusing on the higher or lower portions of the spectrum. Further, we should expect to find differences in degree and direction of ear advantage, even given focusing on the identical portions of the spectrum, with changes in overall performance level.

If the present anisotropy does indeed apply to verbal materials also, it could form the basis for shifts in direction of ear advantage associated with task factors. A good illustrative example is provided by the findings of Haggard and Parkinson (1971). Subjects were presented with sentences that were delivered in various emotional tones to one ear, while babble was presented to the other ear. The subjects were required to identify both the presented sentences and also their emotional tones. A left ear advantage was found for the latter task, but no ear advantage for the former. This type of finding is generally taken to indicate differential involvement of the two hemispheres in extracting various types of information from speech. However, although the identical stimulus patterns were employed in both cases, we might expect that the subjects would have focused on different components of the spectrum in performing the two tasks. For example, they may have utilized relatively more high frequency information for sentence identification and relatively more low frequency information for identification of emotional tone. The one anisotropy could, therefore, have led to different patterns of ear advantage in the two cases.

A similar line of reasoning may be advanced in considering the findings of Bartholomeus (1974). In this experiment, subjects were presented with dichotic pairs of melodies, which were sung to different sequences of letters by different singers. The subjects were required to recognize separately the melodies, the letters, and the singers' voices. A left ear advantage was obtained for melody and voice recognition; however a right ear advantage was obtained for voice recognition. Here again, focusing on different portions of the spectrum in performing these three tasks could have led to different patterns of ear advantage, all based on the same anisotropy.

Differences depending on category of listener may be analogously explained. In the case of musical materials, Gordon (1975) and Johnson (1977) found different patterns of ear advantage for dichotically presented melodies depending on whether or not the subjects were musically trained. However, musicians and nonmusicians may tend to focus on different portions of the spectrum in making such judgments. Further, musicians perform at a higher level than nonmusicians on such tasks, and this, as shown above, would be expected to give rise to differences in patterns of ear advantage, even if the same cues were utilized.

Since the anisotropy described here has so far been unrecognized, much further work is required to determine the extent to which it may have been responsible for patterns of ear advantage that have previously been obtained. The brain mechanisms giving rise to the anisotropy await clinical investigation.[4]

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