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Hemispheric Asymmetries in the Perception of Musical Intervals as a Function of Musical Experience and Family Handedness Background

LUCIA A. KELLAR AND THOMAS G. BEVER

Columbia University

This study examines the effect of musical experience and family handedness background on the categorization of musical intervals (two-note chords). Right-handed subjects, who were divided into four groups on the basis of musical training and presence (or absence) of left-handed family members, categorized musical intervals which were monaurally presented to left or right ear. The results, based on consistency and discreteness of categorization, showed: (1) Musicians' performance is superior to nonmusicians'; (2) musicians and nonmusicians differ significantly on their ear of preference; (3) family handedness background significantly affects ear of preference among musicians but not among nonmusicians.

INTRODUCTION

The processes of the two hemispheres in humans do not differ consistently according to stimulus or sense modality. Both a left hemisphere superiority and a right hemisphere superiority can be elicited for linguistic and nonlinguistic stimuli, auditorally or visually presented (Mishkin & Forgays, 1952, but Heron, 1957. Milner, 1954, 1960; Kimura, 1960; but Krynicki, 1976; Patterson & Bradshaw, 1975; Shankweiler & Studdert-Kennedy, 1967; Kimura, 1961, but Blumstein & Cooper, 1974). Rather, left hemisphere functioning is relational, analyzing the internal structure of the components of the stimulus, while right hemisphere functioning is holistic and operates on the overall contour of the stimulus.

Further, the task requirements of the experiment and the task-relevant

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Address reprint requests to Lucia A. Kellar, Department of Neurology, Neuropsychology Unit, 550 First Avenue, New York, NY 10016.

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experience of the subject can govern which kind of process the subject uses: the same stimulus might be analyzed relationally or holistically depending on the task set by the experimenter, or the subject's prior training (Papcun, Krashen, & Terbeek, 1971; Bever & Chiarello, 1974; Gordon, 1975; Bever, Hurtig, & Handel, 1976; Krynicki, 1976).

Finally, the subject's family handedness background (as well as the subject's own handedness) appears to influence the extent to which the different kinds of processes are lateralized. The presence of left-handedness in the family of a right-handed subject is associated with a reduction in the degree of lateralization of a function in that subject, or a reversal of normal asymmetry (Luria, 1947; Zangwill, 1960; Zurif & Bryden, 1969; Hecaen & Sauget, 1971; Hines & Satz, 1971; Bryden, 1973; Varney & Benton, 1975; Lake & Bryden, 1976).

Thus, three factors are important in assessing an individual's performance in relation to cerebral functioning: type of processing (relational or holistic), amount of task-relevant experience, and family handedness background. The present study was designed to investigate the interaction of these factors in the processing of simple musical stimuli. It addresses two questions. The first is the degree to which experience relevant to the experimental task influences asymmetries of performance, as determined by ear preference. Bever and Chiarello (1974), Gordon (1975), and Johnson, Bowers, Gamble, Lyons, Presbrey, & Vetter (1978) show that a listener's musical experience affects perception of melodic stimuli. For chordal stimuli, Gordon (1970, 1978) found a left ear superiority among musicians, but no ear differences among nonmusicians on a dichotic task. Aiello (1976) found a right ear superiority among nonmusicians but no ear differences among musicians for monaurally presented chords which were of the same key but different internal structure. The present study seeks to determine whether a single set of stimuli and a single procedure can elicit significant, opposite ear preferences for chordal stimuli in two groups which differ in musical experience.

The second question this study addresses is the effect of family handedness history on lateralization of function. Previous studies on the lateralization of musical function have not controlled the factor of history of family handedness. Generally, subjects are classified as right-handed (or left-handed) without any further inquiry into family history of handedness. This factor may account for some of the disparate findings of different investigators.

In this experiment, right-handed subjects are divided into "pure" and "mixed" groups according to whether they had (respectively) only right-handers in their immediate families, or left-handers and ambidexters as well. The purpose of this was to determine whether family history of handedness affects performance on musical tasks, as it seems to on tactual, visual, and other auditory tasks.

METHODS

Subjects. Sixty-four right-handed subjects with no known hearing deficit participated in the experiment. Subjects ranged from the age of 17 to 39, and were primarily drawn from the college population. They were paid for their participation. Thirty-two of the subjects were musicians with at least 10 years of instrumental playing or singing experience and formal instruction. The other 32 were nonmusicians with no musical training or occasional lessons when they were young. Subjects were further classified according to the handedness of members of their immediate family (parents, grandparents, and siblings) by means of a questionnaire adapted from Oldfield (1971) and Crovitz and Zener (1962). Half of the musicians and half of the nonmusicians had only right-handed family members. They were designated "pure." The other half of each group had at least one left-handed, or ambidextrous parent, grandparent, or sibling. These subjects were designated "mixed." Eight members of each of the four subgroups were male and 8 were female.

Stimuli. The 12 stimuli consisted of pairs of simultaneously sounded pure tones. Their composition is displayed in Fig. 1. The lower tone of each pair, 256 Hz, corresponds to the musical note, middle C. The upper tones fall within the range of the note F (342 Hz) through the note G above middle C (384 Hz): Stimulus 1 corresponds to the C–F, an interval of a fourth; Stimulus 6 corresponds to C–F#, an interval of an augmented fourth; Stimulus 12 corresponds to C–G, an interval of a fifth.

The component notes were recorded from a sine wave generator. The 12 stimuli were then constructed such that each pair of tones began in phase, had simultaneous onset and offset, and lasted 500 msec. From these, two tapes, each containing 9 sets of 12 stimuli, were made. Each of the 18 sets of stimuli was in a different, semirandomly determined order. Stimuli were recorded in stereo, one tone on channel one, the other on channel two. They were constructed and taped at Haskins Laboratory, New Haven, Connecticut.

Apparatus. Tapes were played on a Sony TC-180 tape deck and monaurally mixed by means of a modified Koss Connector t-4. Subjects listened over Grayson Stadtler TDH49-10Z headphones which had been disconnected at one ear. The sound pressure level was 76 db, meter slow, scale A.

Procedure. Subjects were tested individually in a small experimenting room. They were told that they would hear five "beeps," which they should encode as "A," followed by a second set of five "beeps" which they should encode as "B," followed by a third set of five "beeps" which they should encode as "C." It was pointed out that "A," "B," "C" were not the musical notes A, B, and C, but arbitrary category names. Subjects were instructed that, following this, they would hear 12 single "beeps," and that their task was to assign each one to category A, B, or C. In case a "beep" did not seem exactly to match A, B, or C, they were to assign it to the category which was closest. No additional criteria (e.g., pitch) were given for category assignment. The examples of A, B, and C preceded each of the 18 sets of 12 trials. Subjects listened monaurally, switching the orientation of the headphones following each set of 12 trials. Thus half the sets were presented to the left ear, half to the right. A questionnaire on the subject's handedness and the handedness of family members was filled out of the time of testing. There were no differences in strength of right-handedness among the eight subgroups.

STIMULUS #	1	2	3	4	5	6	7	8	9	10	11	12	
Upper tone	342	346	350	354	358	362	366	370	374	378	382	384	Hz
Lower tone	256	256	256	256	256	256	256	256	256	256	256	256	Hz

FIG. 1. Components tones of the two-note chordal stimuli.

SCORING

Subjects were scored for the consistency with which they categorized stimuli by means of procedures developed to analyze these data. There were four scores for each subject. Two of these—*overall category variance score* and *overall stimulus variance score*—were a measure of the goodness of overall performance. They were arrived at by taking the mean of the left ear and the right ear variance scores. The lower these scores, the better the subject's performance.

The other two scores—*differential category variance score* and *differential stimulus variance score*—were a measure of ear preference. They were arrived at by subtracting variance scores of the left ear from variance scores of the right ear. Thus if a subject categorized more consistently with his left ear than with his right, these differential scores would be positive. If performance with the right ear was superior, the differential scores were negative.

The procedure for deriving these four scores is described more fully, and illustrated by means of hypothetical data, in the Appendix.

RESULTS

Overall performance was analyzed by 2 × 2 × 2 analyses of variance (Musical Training × Sex × Family Handedness Background) using overall category variance scores and overall stimulus variance scores. The results are displayed in Table 1. There was a main effect for musicianship: musicians performed significantly better than nonmusicians. No other main effect or interactions were significant.

Ear preference was also analyzed by 2 × 2 × 2 analyses of variance, using differential category variance scores, and differential stimulus variance scores. The results are displayed in Table 2. Once again, the only significant main effect was for musical training: musicians and nonmusicians differed significantly in their ear of preference, musicians preferring the left ear, and nonmusician performing better while listening with the right ear. t tests were performed to determine whether these ear preferences differed significantly from chance. For the musicians, the differential scores did not differ significantly from 0. For the nonmusicians, both measures of the right ear preference differed significantly from 0. (Differential category variance: $t\ (31) = -2.558$, $p < .05$, two-tailed. Differential stimulus variance: $t\ (31) = -2.401$, $p < .05$, two-tailed).

Family Handedness Background

If family handedness background has an effect upon the degree of lateralization as indicated by ear preference, then one might expect the mean differential ear scores of the musician and nonmusician groups to differ only slightly from zero. The effect of family sinistrality is to reduce or reverse ear preference. Pure musicians were expected to show a sizable left ear preference, and pure nonmusicians, a sizable right ear preference. Yet the musician and nonmusician groups contain an equal number of pure and mixed subjects. Therefore one might expect a small

TABLE 1

A 2 × 2 × 2 ANALYSIS OF VARIANCE (MUSICIANSHIP × SEX × FAMILY HANDEDNESS BACKGROUND) USING OVERALL STIMULUS VARIANCE SCORES (OSVS) AND OVERALL CATEGORY VARIANCE SCORES (OCVS)

		SS		*MS*		*F*	
Source	*df*	OSVS	OCVS	OSVS	OCVS	OSVS	OCVS
Musicians vs. Nonmusicians (Factor A)	1	28.65	62.69	28.65	62.69	14.59*	12.06*
Male vs. Female (Factor B)	1	5.34	15.56	5.34	15.56	2.72	2.99
Pure vs. Mixed Handedness Background (Factor C)	1	3.66	12.02	3.66	12.02	1.86	2.31
A × B	1	.03	.09	.03	.09	.01	.02
A × C	1	.40	.83	.40	.83	.20	.16
B × C	1	.18	.02	.18	.02	.09	.01
A × B × C	1	3.78	8.31	3.78	8.71	1.92	1.60
Error	56	109.98	291.11	1.96	5.20		
Total	63	152.02	390.61				

* $p < .01$.

mean left ear preference for the musician group, and a small mean right ear preference for the nonmusician group. This in fact was true of the musician group, but not of the nonmusician group, suggesting that family handedness background may have had an effect on the former, but not the latter. To test this, musicians were divided into Pure and Mixed Groups and the factor of family handedness background was further assessed by t tests.

The expected difference in direction of scores is shown by both the category and stimulus variance measures: pure musicians show a positive mean score and mixed musicians show a negative mean score. The pure and mixed musicians are significantly different from each other by both the differential category variance measure (t (30) = 2.596, $p < .01$, one-tailed), and by the differential stimulus variance measure (t (30) = 2.054, $p < .025$, one-tailed). The pure musicians' mean score is significantly positive by both differential category and differential stimulus variance measures (differential category variance: t (15) = 2.001, $p < .05$, one-tailed; differential stimulus variance: t (15) = 1.837, $p < .05$, one-tailed). However, although the scores of mixed musicians are in the predicted negative direction, these are not significantly different from 0 by

TABLE 2
A 2 × 2 × 2 ANALYSIS OF VARIANCE (MUSICIANSHIP × SEX × FAMILY HANDEDNESS BACKGROUND) USING DIFFERENTIAL STIMULUS VARIANCE SCORES (DSVS) AND DIFFERENTIAL CATEGORY VARIANCE SCORES (DCVS)

		SS		*MS*		*F*	
Source	*df*	DSVS	DCVS	DSVS	DCVS	DSVS	DCVS
Musicians vs. Nonmusicians (Factor A)	1	2.98	8.53	2.98	8.53	6.28*	7.79*
Male vs. Female (Factor B)	1	0	.68	0	.68	0	.62
Pure vs. Mixed Handedness Background (Factor C)	1	.41	.82	.41	.82	.86	.75
A × B	1	.16	.76	.16	.76	.33	.69
A × C	1	.51	.64	.51	.64	1.08	.59
B × C	1	.22	1.39	.22	1.39	.47	1.27
A × B × C	1	.21	2.22	.21	2.22	.43	2.03
Error	56	26.52	61.31	.47	1.10		
Total	63	31.00	76.35				

* $p < .01$.

either the differential category variance measure ($t = -1.663$) or the differential stimulus variance measure ($t = -.958$).

For nonmusicians, the expected difference between pure and mixed groups is not shown by either differential category variance ($t = .057$) or differential stimulus variance ($t = .066$). By both measures, the pure nonmusicians as expected showed a significant right ear superiority (differential category variance: $t\ (15) = -2.087, p < .05$, one-tailed; differential stimulus variance: $t\ (15) = -1.881, p < .05$, one-tailed). The mixed nonmusicians however, also showed a right ear preference although their scores were not significantly different from 0 on either differential category variance ($t = -1.598$) or differential stimulus variance ($t = -1.504$).

Thus the second factor of interest—the effect of family handedness background upon lateral asymmetries—appears to be an important one among musicians, but not among nonmusicians.

Since musicians and nonmusicians showed a significant difference in the goodness of their performance (as indicated by overall category variance and overall stimulus variance), and a significant difference in their ear of preference (as indicated by differential category variance and differential stimulus variance), tests for the strength of correlation between goodness of performance and ear of preference were performed. Pearson product-moment coefficients of correlation were computed for both category variance and stimulus variance. That is, overall category variance was correlated with differential category variance, and overall stimulus variance was correlated with differential stimulus variance. t tests were performed to test whether the correlation coefficients were significantly different from 0. By both measures, there is a significant negative correlation. (Category variance: $r = -.327$, $p < .01$; stimulus variance: $r = -.288$, $p < .02$.) That is to say, overall, subjects who performed better (had a low overall variance) preferred the left ear (had more positive differential variance scores).

DISCUSSION

There are two separate aspects of the findings of this study which need to be explained. The first is the significant differences in ear preference between musicians and nonmusicians. The second is why there is an effect of family history of handedness among musicians, but not among nonmusicians.

Before addressing these issues directly, however, it is necessary to consider why family handedness background should affect degree of lateralization of function of all. Numerous studies have reported that right-handed subjects with left-handers in their immediate families evidence reduced or reversed lateralization of function compared to right-handed subjects with purely dextral families (e.g., Zurif & Bryden, 1969; Hines & Satz 1971; Bryden, 1973; Varney & Benton, 1975; Lake & Bryden 1976). The finding is simply reported with no attempt of explanation. In fact, a genetic model of handedness and cerebral representation can be usefully applied to provide a plausible explanation of the effect.

Genetic Model

Perhaps the simplest model to adapt for the purpose of explication is that proposed by Annett (1964). In that account, a single gene controls both handedness and cerebral lateralization. The gene has two alleles: a dominant one (D) which manifests as right handedness and a recessive one (R) which manifests as left handedness. The dominant hemisphere (i.e., that in which language function or relational processing is primarily carried out) is linked to handedness so that individuals with DD makeup (dominant homozygotes) will be consistently right-handed and "left hemisphered" for relational processing, and "right hemisphered" for holistic processing. Individuals with RR makeup (recessive homozygotes) will be consistently left-handed and "right hemisphered" for relational processing, "left hemisphered" for holistic processing. Heterozygotes (DR) may develop greater skill in either hand, and relational processing in either hemisphere, but there is a tendency to develop right handedness and left cerebral dominance due to the dominance of D.

It is clear from this that there are two classes of right-handers: homozygotes (DD), in whom relational and holistic processes are strongly lateralized to left and right hemispheres, respectively, and those heterozygotes (DR) who manifest as right-handers but in whom there is less clearly delineated lateralization of processes. In these latter individuals, functions which in a homozygote would be completely lateralized to one or the other hemisphere would here be represented to a greater or lesser degree in both hemispheres. Thus, one would expect heterozygotes to show weaker lateralization of function, behaviorally, than homozygotes.

However, it is not possible to select subjects on the basis of homo- or heterozygosity. All right-handers with purely dextral background are not homozygotes; nor are all right-handers with sinistrality in their family backgrounds heterozygotes. However on the basis of breeding ratios given within the model, one can predict that a group of right-handers with only right-handers in their family background will contain about 80% homozygotes and 20% heterozygotes. Similarly, one can predict that a group of right-handers with sinistrality and ambidexterity in their family backgrounds will be made up of 50% heterozygotes and 50% homozygotes.

In neither this nor earlier studies had the difference between the pure and mixed groups been a very strong one; in fact, some studies have reported no differences. Furthermore although significant differences between pure and mixed groups have been reported, a significant reversal of side of preference had never been noted (e.g., the mixed group of musicians showed a right ear preference, but it was not significantly different from zero). Consideration of the makeup of the pure and mixed groups helps to understand these findings. One should not expect to find a strong overall difference between the mixed and pure groups, since both groups contain both homo- and heterozygotes, in different proportions. Nor should one expect a significant reversal in side of preference in the mixed group, since a full half of that group are probably homozygotes. On the other hand, one would expect the strength of the side of preference of the pure group to be significant since the proportion of homozygotes (80%) is so high.

Account of the Findings

Nonmusicians as a group showed a clear right ear superiority, reflecting left hemisphere processing. Musicians as a group showed an insignificant left ear (right hemisphere) superiority, and among pure musicians, this preference was statistically significant. This difference can be interpreted according to the difference between relational and holistic processing.

The experimental task is a difficult one, requiring not only fine discrimination among different musical intervals, but assignment of these to categories which must be held in short-term memory for a considerable length of time. For nonmusicians, both the categories and the task of assignment are novel, and require internal analysis of note relationships, since these subjects have no templates of interval types which might allow holistic matching. Hence, these subjects show a right ear preference reflecting relational processing by the left hemisphere. Although there is not a statistically significant difference between the pure and mixed groups of nonmusicians, the pure group had differential category and stimulus means which were significantly different from 0 but the mixed group's means were not statistically significant, possibly reflecting a slightly weaker asymmetry. This would accord with Annett's genetic model which includes more heterozygotes in the mixed group than in the pure group and so would predict less asymmetry of cerebral representation for the mixed group as a whole.

For musicians on the other hand the categories are commonly encountered musical intervals learned in the course of their training, and the task is similar to the sort of discriminations which must be made in the course of their musical activity. Their training has allowed them to develop Gestalten—entities such as "interval of a fifth," "interval of a fourth," etc.—by which they can match the test stimuli in a holistic manner, bypassing internal analysis of the component notes.

These two different strategies for performing the experimental task, because they call upon processes lateralized in opposite hemispheres, give rise to different ear superiorities. Nonmusicians, because they must depend on relational processing of the left hemisphere, show a contralateral right ear superiority. Musicians, who have developed templates of interval types, make greater use of the holistic process normally lateralized in the right hemisphere. But the musicians as a group do not show a significant left ear superiority. Or, put another way, one segment of the musician group (the pure musicians) shows a decided left ear superiority, but the other (the mixed group) does not. There is no immediately obvious explanation for this, but the following is a possible one.

One could assume that, prior to any musical training, a task such as the one in this experiment requires internal analysis of interval relations. Such analysis draws upon the relational processing of the left hemisphere and so gives a right ear superiority. Musical training and experience is accompanied by better performance on such a task and the development of interval templates with a concomitant shift to the holistic processing of the right hemisphere. That this is generally so is attested by the significant correlation between goodness of performance and left ear superiority over all subjects. However, in homozygotes, in whom relational and holistic processes are well lateralized, this switch to holistic processing necessarily involves a shift from left hemisphere to right hemisphere functioning, and hence, a clear left ear superiority. In heterozygotes, because of the more bilateral representation of the two processes, holistic processing can develop in the hemisphere they use initially (the left), and so results in little or no shift to the right hemisphere. Thus, in musicians, where a shift in type of processing has occurred, differences in the cerebral organization of homo- and heterozygotes (as reflected in pure and mixed groups) are evident. In nonmusicians, who are confined to the use of relational processing for this task, no significant differences are evident.

Such an explanation is not wholly satisfactory. It does not clearly account for the findings of some of the earlier studies which found performance differences associated with family handedness history. These studies, however, use much simpler tasks, for which it is difficult to define or assess subjects' relevant experience.

The explanation clearly needs to be tested with additional research. One obvious extension of this study would be a similar one using melodic stimuli. Experienced musicians with sinistrality in their immediate families would be expected to show less of a right ear superiority for the recognition of melodies than musicians with a purely dextral background.

CONCLUSION

This study set out to assess the effects of task-relevant experience and family handedness background in lateralization of cerebral processes. The finding of a clear-cut difference in ear preference (reflective of cerebral processing) as a function of musical experience clearly indicates that task-relevant experience is a factor that must be taken into account when studying cerebral lateralization. It also further supports the notion that the different processes of left and right hemispheres are neither stimulus nor modality specific. The same musical stimuli were capable of eliciting both a right and a left ear superiority. Although a satisfactory explanation for the differences found as a function of family handedness history will depend upon further research, the fact that such differences were found indicates that this also is a factor which must be attended to in future studies.

In most studies to date, the type of processing can usually be inferred from the description of the experimental task. However, subjects' experience and family handedness background are rarely known or reported. Since these factors interact with the type of process a subject employs, as this study demonstrates, it is difficult to assess or interpret the results previously reported. Although the results of this study cannot be conclusively explained at this point, they clearly indicate that both task-relevant experience and family handedness history are factors that must be taken into consideration in an account of hemispheric functioning.

APPENDIX

Scoring Procedure

Subjects were scored in two ways for the consistency with which they categorized stimuli.

Category Variance

The variance of categories A, B, and C was computed for the left and the right ear of each subject. By way of illustration, consider the hypothetical data displayed below: The category A variance for the left ear was computed as follows: 1 was entered nine times, 2 was entered nine times, 3 was entered nine times, and 4 was entered nine times, because the subject called Stimuli 1, 2, 3, and 4 "A" all nine times when listening with the left ear. The variances of category B and of category C for the left ear, and the variances of categories A, B, and C for the right ear were similarly computed. Then a mean variance score for the left ear was calculated by taking the mean of the three variances (one for each category) of the left ear. A similar mean was calculated for the right ear. Thus each subject has a mean category variance score for the left ear, and one for the right ear.

These scores reflect consistency of categorization. The more consistently a subject categorized, the lower will be his variance score, except for a possible artifact discussed below. Thus in the hypothetical data the left ear would have a lower mean variance score than the right ear, because Stimuli 4 and 8 were categorized less consistently with the right ear than with the left.

The left and right ear category variance scores were then used in two

Frequency Distribution of Assignment of 12 Stimuli to Categories A, B, and C for Left and Right Ears

	Left ear			Right ear		
Category Stimulus	A	B	C	A	B	C
1	9	0	0	9	0	0
2	9	0	0	9	0	0
3	9	0	0	9	0	0
4	9	0	0	5	4	0
5	0	9	0	0	9	0
6	0	9	0	0	9	0
7	0	9	0	0	9	0
8	0	9	0	0	5	4
9	0	0	9	0	0	9
10	0	0	9	0	0	9
11	0	0	9	0	0	9
12	0	0	9	0	0	9

ways: (1) The mean of the variance scores of the two ears was computed for each subject as a measure of his overall level of performance. This score is called the *overall category variance score*. The higher this score, the less consistent (worse) the overall performance. (2) The second way the scores were used was as a measure of ear preference. The score of the left ear was subtracted from the score of the right ear. This score is called the *differential category variance score*. Thus, if a subject categorized more consistently with his left ear than with his right ear, the difference score would be positive. If he performed better with his right ear, the difference score was negative.

Thus each subject had two scores based on category variance: an *overall category variance score*, reflecting goodness of performance, and a *differential category variance score*, reflecting ear preference.

This procedure for scoring is able to capture the consistency with which each individual stimulus was categorized, as well as the discreteness with which the continuum (represented by Stimuli 1–12) was broken into categories. That is, inconsistency in the categorization of each individual stimulus will add to the category variance. In addition, the spread of a given category will affect the size of the category variance. For instance, if Stimulus 1 and Stimulus 12 are both consistently categorized as "A," it will add much more to the category variance than if Stimulus 1 and Stimulus 2 are consistently categorized as "A."

However, this procedure for scoring introduces unwanted "noise," in that the width of the category affects the size of the score. Thus, for the hypothetical data presented the left ear score is greater than 0, even though the subject was completely consistent in setting category boundaries between Stimuli 4 and 5 and Stimuli 8 and 9.

When the category variance is used to determine ear preference by subtracting a subject's left ear score from his right ear score, this noise factor should not matter very much. For the hypothetical data, the category boundaries for the two ears were at the same point, but with unequal consistency. Thus, the variance contributed by the width of the category factors out. The only instance in which the width of the categories might artifactually affect the score is one in which a subject set different boundaries for the left and the right ears. There is no reason to expect this to happen and no evidence that it actually occurred in the data. However, it remains a possible source of artifact.

When category variance is used to assess overall performance by taking the mean of the left and the right ear scores, the width of the categories does affect the score in an unwanted way. For instance, if two subjects were equally consistent in their parsing of the continuum, but one set boundaries between Stimuli 2 and 3 and Stimuli 10 and 11, he would have a greater mean score than the other who set the boundaries between

Stimuli 4 and 5 and Stimuli 8 and 9. This difference would be solely a function of category width.

Consequently, a second measure—stimulus variance—is also used. However, because category variance takes into account how the continuum is broken up, and stimulus variance does not, category variance as well as stimulus variance is used in the analysis of the results.

Stimulus Variance

Stimulus variance measures only how consistently a given stimulus was assigned to one of the three categories and does not take into account how consistently the entire continuum is divided up. A stimulus variance score was computed for the left and right ears of each subject. This was done by considering category A as 1, category B as 2, and category C as 3. The variance for each of the 12 stimuli in the left ear was calculated, and the sum of the 12 variance scores yielded a left ear score. Similarly, the variance for each of the 12 stimuli in right ear listening was computed, and their sum was the right ear score. Thus, each subject has a stimulus variance score for the left ear and for the right ear.

These scores were then used in two ways: (1) The mean of the scores of the two ears was computed for each subject as a measure of overall level of performance. This score is called the *overall stimulus variance score*. As in the case of overall category variance, the higher a subject's score, the more inconsistent, and so worse, his performance. (2) The second way in which the scores were used was as a measure of ear preference. The left ear score was subtracted from the right ear score. The resulting score is called the *differential stimulus variance score*. If a subject categorized stimuli more consistently with his left ear, this difference score would be positive. If he categorized more discretely with his right ear, the score was negative.

Thus, each subject had two scores based on stimulus variance: the *overall stimulus variance score,* reflecting goodness of performance, and the *differential stimulus variance score,* reflecting ear preference.

Altogether, a subject had four scores, overall and differential category variance scores, and overall and differential stimulus variance scores.

Note added in proof. The authors were unaware of the model which Annett proposed in 1972 at the writing of this paper. That model proposes a single gene which causes a shift to right-handedness and left hemisphere dominance; left-handedness is not under direct genetic control. This model, like the 1964 model, is able to account for the differences between groups of Pure and Mixed right-handers reported here. In the 1964 model, the differences are due to differing proportions of (a) homozygous and (b) heterozygous right-handers. In the 1972 model, the differences are due to differing proportions of (a) right-handers with the "right shift" gene, which causes left hemisphere dominance, and (b) "accidental" right-handers, who lack the "right shift" gene, and who thus may have quite variable dominance.

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