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Are Variations among Subjects in Lateral Asymmetry Real Individual Differences or Random Error in Measurement?: Putting Variability in Its Place

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The current research investigates sources of variability in subjects' asymmetry scores on commonly used laterality tasks. In particular, subjects' asymmetry scores on four bilateral tachistoscopic tasks and one free-vision task were entered into a principal component analysis (PCA) in order to investigate components that explain the maximum variance of the sample. The results indicate that about half of the variation (45.2%) in asymmetry scores on both tachistoscopic and free-vision tasks is attributable to individual differences in characteristic perceptual asymmetry. The amount of variance explained by this characteristic perceptual asymmetry component is similar in a sample of dextrals and a sample of sinistrals. No significant relation was revealed between individual differences in characteristic perceptual asymmetry and performance on various verbal and spatial cognitive tasks. © 1990 Academic Press, Inc.

Perceptual asymmetries of normal dextrals as indexed by laterality tasks (e.g., dichotic listening, lateralized tachistoscopic presentation) are

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extremely variable in both magnitude and direction. In particular, only about 70% of subjects show the expected left hemisphere superiority for processing certain linguistic stimuli and right hemisphere superiority for processing certain visuospatial and musical stimuli (e.g., Bryden, 1976; Kimura, 1961, 1964). In contrast, sodium amytal tests carried out on patients with intractable focal epilepsy indicate that at least 95% of dextrals have left hemisphere dominance for speech (Wada & Rasmussen, 1960; Rasmussen & Milner, 1975). Further evidence for the consistency of differential left hemisphere involvement in both receptive and productive aspects of language comes from the rarity of aphasic symptoms following right hemisphere damage in dextrals (e.g., Weisenberg & McBride, 1935; Kimura, 1983a) as well as from studies of commissurotomy patients (e.g., Levy, Trevarthen, & Sperry, 1972; Sperry, 1974).

Various explanations for the discrepancy between the laterality findings with normal adults and brain damaged patients have been proposed. First, the variability in normal subjects' asymmetry scores has been attributed to the unreliability of laterality tasks (e.g., Chiarello, Dronkers, & Hardyck, 1984; Hines & Satz, 1974; Teng, 1981). However, some laterality tasks have been shown to be highly reliable (e.g., Levine & Levy, 1986; Wexler, Halwes, & Heninger, 1981), and even for these, the magnitude and direction of subjects' asymmetry scores does not correspond well with the clinical data. For example, Wexler, Halwes, and Heninger (1981) report a test–retest reliability of .91 for their dichotic listening test, yet 23% of dextral subjects in this study (computed from Fig. 1, Wexler et al., 1981) showed a reversed direction of asymmetry. Thus, it cannot be assumed that the variability in lateral asymmetry among dextrals is mainly attributable to random error in measurement.

Second, it has been suggested that dextrals may vary continuously in underlying hemispheric specialization with a majority showing left hemisphere specialization for language functions and right hemisphere specialization for visuospatial functions (e.g., Chiarello, 1988; Shankweiler & Studdert-Kennedy, 1975). Although individual differences in hemispheric specialization may account for some of the variation in asymmetry scores among dextrals, the proportion of normal dextrals with a reversed direction of asymmetry on laterality tasks far exceeds what would be predicted by clinical data obtained from epileptic and other brain damaged patients (Wada & Rasmussen, 1960; Rasmussen & Milner, 1975). It is possible that the discrepancy stems from the use of different tasks in studies of clinical and normal populations (e.g., productive vs. comprehensive linguistic tasks). It also is possible that patterns of hemispheric specialization in clinical patients are altered by adaptations to long-standing brain damage. Despite these differences, however, it is generally acknowledged that the wide discrepancy between asymmetry data obtained from normal dextrals vs. brain damaged patients cannot be fully accounted for by wide variations in hemispheric specialization among dextrals.

An alternative hypothesis for the discrepancy has been proposed by Levy, Heller, Banich, and Burton (1983a). According to this hypothesis, the discrepancy is attributable to large individual variations among dextrals in characteristic arousal asymmetry. Levy et al. (1983a) use "characteristic arousal asymmetry" to refer to a stable individual trait in the relative arousal levels of the two hemispheres. They argue that the existence of variations in hemispheric arousal asymmetries among dextrals is supported by data from a variety of sources, including baseline EEG (e.g., Bakan & Svorad, 1969; Ehrlichman & Wiener, 1979; Morgan, McDonald, & Macdonald, 1971), baseline cerebral blood flow (e.g., Dabbs & Choo, 1980), and lateral eye movements in the experimentor-facing-subject condition (e.g., Gur, Gur, & Harris, 1975). Evidence that this arousal asymmetry is a stable characteristic of an individual emerges from the relatively high reliabilities of these measures (Bakan & Strayer, 1973; Dabbs & Choo, 1980; Ehrlichman & Wiener, 1979). For example, Ehrlichman and Wiener (1979) report a test–retest reliability of .88 for EEG asymmetry measures obtained on 11 normal dextrals.

Levy et al. (1983a) suggest that a subject's "characteristic arousal asymmetry" leads to a "characteristic perceptual asymmetry" in favor of the sensory half-field contralateral to the more aroused hemisphere. They also suggest that underlying hemispheric specialization is more or less invariant across dextrals, whereas characteristic arousal asymmetry is highly variable across dextrals, ranging from strong right hemisphere arousal asymmetry through nearly equal arousal asymmetry to strong left hemisphere arousal asymmetry. According to this hypothesis, a normal dextral's asymmetry score on a particular laterality task reflects his/her characteristic arousal asymmetry as well as his/her underlying hemispheric specialization for the information processes applied to that task. However, the between-subjects variation in dextrals' asymmetry scores is accounted for more by variations in characteristic arousal asymmetry than by variations in underlying hemispheric specialization.

Levy et al.'s hypothesis leads to the prediction that there should be a positive covariation between subjects' asymmetry scores on left hemisphere specialized, right hemisphere specialized, and nonlateralized tasks (asymmetry scores computed as right visual field (RVF)–left visual field (LVF) for all tasks). To the extent that such a positive relation is found, it can be assumed that subjects' "characteristic perceptual asymmetries" operate similarly across different tasks. Thus, while the mean asymmetry score for a group of dextrals shifts depending on whether the task is left hemisphere specialized, nonlateralized, or right hemisphere specialized, a strong version of the arousal hypothesis predicts that individual subjects

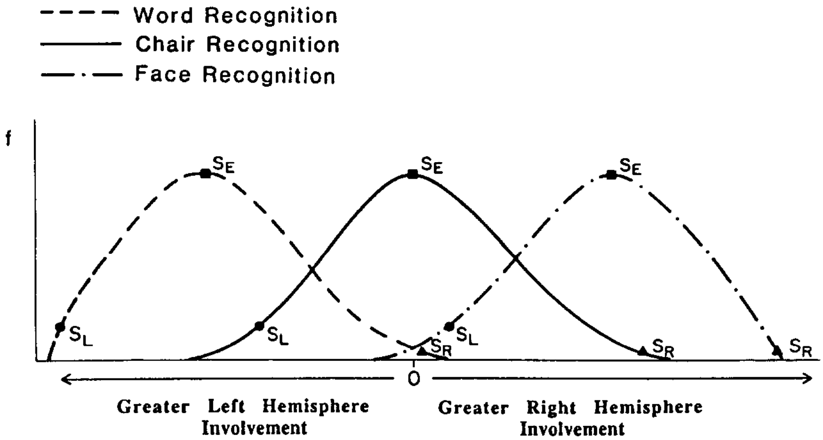

FIG. 1. Asymmetry scores predicted by a strong version of arousal hypothesis of a right hemisphere aroused subject (S_R), a symmetrically aroused subject (S_E), and a left hemisphere aroused subject (S_L) on a left hemisphere specialized word recognition task, a nonlateralized chair recognition task, and a right hemisphere specialized face recognition task.

will maintain the same position relative to other subjects in the distributions of asymmetry scores on each of the laterality tasks presented (see Fig. 1 for hypothetical results predicted by the arousal hypothesis).

Consistent with this prediction, Levy et al. (1983a) report a positive correlation between subjects' asymmetry scores on left and right hemisphere specialized tasks. In addition, Levine, Banich, and Koch-Weser (1984) report a positive correlation between subjects' asymmetry scores on tasks for which the mean asymmetry score for the group is consistent with left hemisphere specialization, right hemisphere specialization, or no significant difference between left and right hemisphere involvement. Levine et al. (1984) hypothesize that subjects' asymmetry scores on tasks that are nonlateralized for the group as a whole reflect individual differences in characteristic perceptual asymmetry rather than random fluctuations around zero.

In the present study, dextrals' and sinistrals' asymmetry scores on multiple laterality tasks were investigated in order to test the hypothesis that a major source of variability in subjects' asymmetry scores is individual differences in characteristic perceptual asymmetry. This was done in two ways. First, we used subjects' asymmetry scores on a nonlateralized task as an index of their characteristic perceptual asymmetry (Levine et al., 1984). We then determined whether this index of characteristic perceptual asymmetry predicted subjects' asymmetry scores on left and right hemisphere specialized tasks. Second, we applied a principal component analysis (PCA) to subjects' asymmetry scores on all of the laterality tasks administered to determine whether a component consistent with the hypothesis of characteristic perceptual asymmetry would emerge.[1] If individuals vary widely in characteristic perceptual asymmetry as Levy et al. (1983a) hypothesize, a component should emerge on which all laterality tasks load in one direction with similar weights.

Characteristic perceptual asymmetry may reflect central factors such as hemispheric arousal/attentional asymmetry (Levy et al., 1983a) and/or peripheral factors such as asymmetric sensory pathway dominance (cf. Hellige, Bloch, & Taylor, 1988; Segalowitz, 1987). Administration of lateralized tachistoscopic tasks as well as the free-vision facebook task should allow us to determine whether central factors play a role in subjects' characteristic perceptual asymmetries. The free-vision task does not involve lateralized input (see description below), and therefore, even if asymmetric pathway dominance plays a role in subjects' characteristic perceptual asymmetries, it would play less of a role on the free-vision task than on the tachistoscopic tasks. Thus, the view that asymmetry in central factors underlies characteristic perceptual asymmetry would be supported by significant correlations between subjects' asymmetry scores on the free-vision and tachistoscopic tasks.

The present study also investigates whether the distribution of characteristic perceptual asymmetries among sinistrals is comparable to the distribution of characteristic perceptual asymmetries among dextrals. Though the distribution of typical and atypical hemispheric specialization is known to differ between dextrals and sinistrals (e.g., Rasmussen & Milner, 1975), this might not be the case for characteristic perceptual asymmetry. On the view that individual variations in hemispheric specialization and characteristic perceptual asymmetry are related, the distribution of characteristic perceptual asymmetries also may differ between dextrals and sinistrals. On the other hand, on the view that individual variations in hemispheric specialization and characteristic perceptual asymmetry are independent, the distribution of characteristic perceptual asymmetries may not differ between dextrals and sinistrals.

Finally, the present study investigates whether variations in characteristic perceptual asymmetry are related to individual differences in cognitive ability patterns. It is possible that individual differences in characteristic perceptual asymmetry are correlated with different cog-

[1] A PCA computes uncorrelated linear combinations of the original variables that account for the maximal variance in the sample (Johnson & Wichern, 1982). Although as many components as original variables are required in order to account for 100% of the variance, often much of the variability can be accounted for by a small number of the first few principal components. Thus, a PCA attempts to replace a large number of correlated variables with a small number of uncorrelated components. The solution may provide an increased understanding of significant underlying factors (Green, 1978).

nitive ability patterns, particularly if characteristic perceptual asymmetry reflects central factors. Alternatively, it is possible that different patterns of cognitive ability are related to variations in hemispheric specialization, but not to variations in characteristic perceptual asymmetry. The absence of a significant relation between asymmetry scores and cognitive abilities, reported in many studies in the literature (for a review, see Beaumont, Young, & McManus, 1984; Lewis & Harris, 1988), may be attributable to a larger proportion of the variance in subjects' asymmetry scores reflecting individual differences in characteristic perceptual asymmetries than differences in hemispheric specialization.

METHOD

Subjects

Subjects were recruited from the University of Chicago community. The sample included 63 adults (14 dextral males, 17 dextral females, 16 sinistral males, 16 sinistral females) ranging in age from 17 to 40 years with a mean age of 21.4 years. Subjects were classified as dextrals and sinistrals according to their writing hand and a six-item questionnaire (throwing ball, using hammer, brushing teeth, dealing cards, soup spoon, and sawing). Any subject who wrote with the right hand, and carried out at least five of the six activities with their right hand was classified as a dextral. Any subject who wrote with the left hand, regardless of hand preference on the questionnaire, was classified as a sinistral as sinistrals are known to have more inconsistent hand preferences than dextrals (Oldfield, 1971). In fact, hand preference as assessed by our six-item questionnaire indicated that dextrals had more consistent hand preferences (right hand preference: mean = 5.84, SD = .37) than sinistrals (left hand preference: mean = 4.93, SD = 1.32). All subjects had normal or fully corrected vision according to self-report.

Tachistoscopic Laterality Tasks

Stimuli. Stimuli were bilaterally presented to binocular view in a Gerbrands two-channel tachistoscope (Model T-2B1). Four different stimulus types were used: line drawings of common objects, four- and five-letter words, photographs of faces, and photographs of chairs. The line drawings were black ink line drawings of common objects (Levine & Banich, 1982). The words were names of common objects that were aligned vertically and typed in black capital letters (IBM Bookface). The photographs of faces and chairs were black and white front view pictures of previously unfamiliar faces and chairs. Stimuli were placed symmetrically on white stimulus cards, one member of each pair appearing in the LVF and the other in the RVF. The medial edge of each member of a stimulus pair was approximately 1° 20′ from the center of fixation for words, 1° 30′ for faces, 2° 10′ for chairs, and 2° 20′ for line drawings. Maximal horizontal visual angle ranged from 20′ for words to 3° 40′ for faces. Maximal vertical visual angle ranged from 2° 20′ for line drawings to 3° 50′ for faces. One of six symbols (+, =, Δ, ∞, *, o) appeared at the center of each stimulus card.

For chairs and faces, two choice arrays of 12 pictures were formed. For each choice array, nine bilateral stimulus pairs were constructed using 8 pictures twice, 2 once, and 2 never, in order to discourage a guessing strategy for picture pairs shown late in the series.

Procedure. Each subject was tested in two sessions. In the first session, the tachistoscopic and free-vision facebook tasks were administered. The tachistoscopic tasks were always presented first. Within the tachistoscopic tasks, the chair and line drawing tasks were always administered first with the order of these two tasks counterbalanced across subjects. These tasks have been reported to be nonlateralized for dextral adults (Levine & Banich, 1982; Levine et al., 1984). Next, the face and word laterality tasks, previously reported to differentially involve the right and left hemispheres, respectively (Levine et al., 1984), were administered. The order of the face and word tasks also was counterbalanced across subjects. Within each stimulus type, items were presented in a fixed random order, with the left–right position of the members of each stimulus pair counterbalanced across subjects.

For each stimulus type, subjects were presented with 12 practice trials immediately followed by 18 test trials. Subjects began each trial by viewing a preexposure field consisting of the outline of a small black rectangle at the center of the field. The stimulus card appeared 500 msec after the subject initiated a trial by depressing a telegraph key, simultaneous with the offset of the fixation field. On each trial, the subject's first task was to identify the symbol which appeared at the fixation point and then to report the lateralized stimuli. Accurate report of the central symbol served as an index of central fixation. Trials on which this symbol was reported incorrectly were excluded and administered again at the end of each block. For line drawings and words, subjects reported the stimuli verbally. For chairs and faces, subjects were presented with a 12-item array following the presentation of each stimulus. The subject's task was to select the two items presented from the array. Subjects were allowed to point to the items with either hand.

Because asymmetry scores may be sensitive to overall accuracy (Levy et al., 1983a), exposure duration was varied from trial to trial in an attempt to equate overall performance level across both subjects and stimulus types. Based on pilot work, the starting exposure duration in the practice trials was set at 180 msec for words, 60 msec for chairs, 80 msec for faces, and 60 msec for line drawings. Exposure duration remained the same if a subject responded correctly to one item of a pair, was increased by 10 msec if both items were missed, and was decreased by 10 msec if both items were correct. However, the exposure duration was never allowed to exceed 200 msec which is considered to be the latency to initiate an eye movement (Pirozzolo & Rayner, 1980).

Free-Vision Chimeric Facebook Task

Following the tachistoscopic tasks, subjects were given Levy, Heller, Banich, and Burton's (1983b) chimeric facebook task. Neutral and smiling photographs of each of nine male posers were used to construct 36 items. The two photographs of each poser were cut in half on the midsagittal axis and recombined to make two different chimeras, one with the smile produced by the left half of the poser's face and the neutral expression produced by the right half, and vice versa for the other chimera. Each of these chimeras was paired with its mirror image, once with the normal print at the top of the page and the mirror print at the bottom, and once with the positions reversed. This yielded a total of 36 items, four pairs of stimuli for each of the 9 posers. Each poser appeared once in each quarter (nine trials) of the task. The subject's task on each of the 36 trials was to decide which of two mirror-imaged chimeras looked happier. Subjects were allowed to give a "can't decide" response in the event that no decision was possible. Rightward responses were those in which the chimera with the smile to the subject's right was chosen as looking happier, and vice versa for leftward responses.

Cognitive Tests

The following cognitive tasks were administered in the second session which was held at most 1 week after the first session.

Digit span. The Digit Span subtest of the Wechsler Adult Intelligence Scale (Wechsler, 1955) was administered according to the standardized test instructions. Forward and backward digit spans were scored separately. For each sequence repeated correctly, a subject was given 1/2 point. For example, if a subject correctly repeated both lists at length six, one of two lists at length seven, and none at length eight, his/her score would be 6.5.

Mental rotations test. This test was administered according to the standardized instructions (Vandenberg & Kuse, 1978). The test consisted of 20 items. On each item the subject was presented with a two-dimensional drawing of a three-dimensional block structure. The subject's task was to match the target item to two of four choices which represented the same structure, in a different orientation in three-dimensional space. The remaining distractors represented block structures which differed in shape from the target structure. An item was counted as correct only if both choices were identified correctly. One point was given for each item responded to correctly, yielding a maximum score of 20.

Face recognition test. This test was an adaptation of Yin's (1970) technique for assessing subjects' recognition memory for upright and inverted faces. Thirty-six front view photographs of male faces served as test items. In the first part of the test, an inspection series of 18 faces was presented one at a time in the upright orientation for 3 sec each. Immediately following the presentation of this series, subjects were presented with 18 pairs of upright faces. The subjects' task was to decide which member of each pair had appeared in the inspection series. The second part was identical except that both inspection and test series were presented in the inverted orientation and a different set of 18 faces was used. One point was given for each face correctly recognized in each orientation condition. Thus, 18 was the maximum score for the upright faces as well as the inverted faces.

Verbal fluency. Two different verbal fluency measures were used. In the first (Test A), subjects were asked to name as many animals as they could in a 30-sec period (Talland, 1965). In the second (Test B), subjects were asked to name as many words beginning with the letter *h* as they could in a 30-sec period (Borkowski, Benton, & Spreen, 1967). For each task, one point was given for each unique animal or h-word named.

Verbal analogy. This task was adapted from a preparation book for the Miller Analogies Test. A test item consisted of analogy problems of the following sort: QUIXOTIC:IDEALISTIC,CHAUVINISTIC: [(a) apathetic, (b) patriotic, (c) antiestablishment, (d) bucolic]. Each correct response received one point and the maximum score was 24.

For all subjects, the cognitive tests were administered in the following fixed order: Verbal Analogy Test, Mental Rotations Test, Digit Span Forward, Digit Span Backward, Verbal Fluency A, Verbal Fluency B, Upright Face Recognition Test, and Inverted Face Recognition Test.

RESULTS

ANOVA of Tachistoscopic Tasks

An analysis of variance (ANOVA) was performed on accuracy scores in each visual field on the tachistoscopic tasks. Gender and Handedness were between-subjects factors, and Visual Field and Stimulus Type were within-subjects factors. The numbers of stimuli recognized correctly in each VHF were the dependent variables. The main effect of Stimulus Type was significant ($F(3, 177) = 7.263, p < .0001$). This effect indicated that performance levels were not equivalent across Stimulus Types. In particular, performance on the word task (36.0%) was lower than that on the other three tasks (line drawings, 42.5%; faces, 41.5%; chairs, 42.8%). The lower performance on the word task emerged even though the mean exposure duration for the word task was longer than that for the other tasks (words, 183 msec; chairs, 95 msec; faces, 89 msec; line drawings, 85 msec). Many subjects were not able to perform as well on

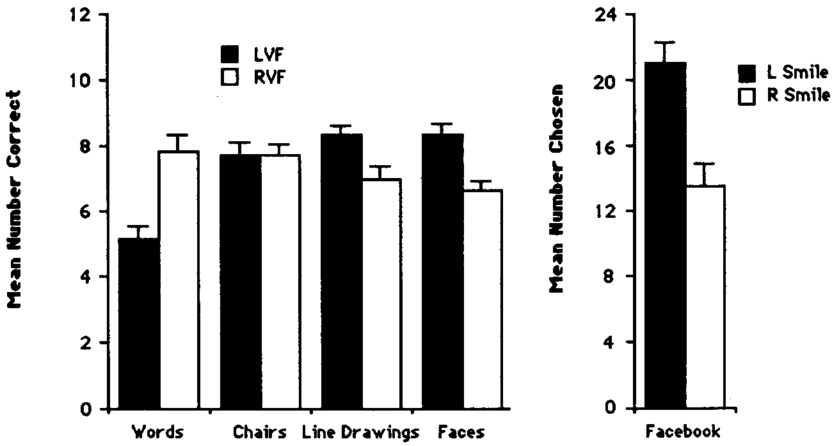

FIG. 2. Mean number of LVF and RVF correct responses for the tachistoscopic tasks and mean number of leftward and rightward responses for the free-vision facebook task.

the word task as on the other tasks even with the maximum exposure duration of 200 msec given for words.

As expected, the interaction of Stimulus Type by Visual Field was highly significant ($F(3, 177) = 16.95$, $p < .0001$) (see Fig. 2). Planned contrasts on each Stimulus Type revealed that on the word task, subjects as a group showed a significant RVF advantage ($F(1, 236) = 21.09$, $p < .0001$). On the face and line drawing tasks, subjects as a group showed a significant LVF advantage (faces: $F(1, 236) = 8.53$, $p < .01$; line drawings: $F(1, 236) = 5.67$, $p < .025$). The results are consistent with the hypothesis that the left hemisphere is specialized for processing verbal information, whereas the right hemisphere is specialized for processing complex visuospatial information. On the chair task, subjects as a group showed no overall visual field advantage ($F(1, 236) < 1$). The obtained asymmetries for faces, words, and chairs replicate the previous report of Levine et al. (1984), whereas the significant LVF advantage for line drawings differs from the finding of no asymmetry reported by Levine et al. (1984). The finding of no asymmetry on the chair task also is consistent with De Renzi and Spinnler's finding (1969) of no difference between the ability of left- and right-brain damaged patients to individuate chairs.

The interaction of Stimulus Type by Visual Field by Gender also was significant ($F(3, 177) = 5.53, p < .01$). Bonferonni tests ($\alpha = .05$) revealed that the interaction of Visual Field by Gender was significant for the word task, but not for the other three tasks. The significant interaction of Visual Field by Gender on the word task reflected the finding that females displayed a larger RVF advantage than males.

Finally, the interaction of Stimulus Type by Visual Field by Handedness was significant ($F(3, 177) = 3.46, p < .05$). Bonferonni tests ($\alpha = .05$) showed that the interaction of Visual Field by Handedness was significant for the face task, but not for the other three tasks. The significant interaction of Visual Field by Handedness on the face task reflected the finding that dextrals displayed a larger LVF advantage than sinistrals.

ANOVA of the Free-Vision Facebook Task

As expected, subjects' mean asymmetry score on the facebook task (R Smile–L Smile) was significantly less than zero ($t(62) = -2.79, p < .005$, one-tailed). This effect indicated that subjects chose chimeric faces with the smile to their left as looking happier more often than chimeric faces with the smile to their right (see Fig. 2). An ANOVA was performed on subjects' asymmetry scores with Gender and Handedness as between-subjects factors. No effects reached significance in this analysis.

Chair Group Analysis

In order to test the hypothesis that subjects' asymmetry scores on laterality tasks reflect individual differences in characteristic perceptual asymmetry, subjects were divided into two groups (Group LChair, Group RChair) on the basis of asymmetry scores on the nonlateralized chair recognition task. Twenty-nine subjects with asymmetry scores in favor of the LVF on this task were classified into Group LChair and the other 26 subjects with asymmetry scores in favor of the RVF were classified into Group RChair. Eight subjects with zero asymmetry scores were not included in the following analysis.

An ANOVA was performed on accuracy scores in each visual field on the tachistoscopic tasks with Gender, Handedness, and Chair Group (LChair, RChair) as between-subjects factors, and Tachistoscopic Stimulus Type (faces, words, line drawings) and Visual Field as within-subjects factors. The chair task was excluded from this analysis, because it was used to group the subjects. As predicted, the interaction of Chair Group by Visual Field was highly significant ($F(1, 47) = 14.60, p < .0005$). This effect reflects the finding that subjects in Group LChair had higher LVF scores and lower RVF scores on all three laterality tasks than subjects in Group RChair (see Fig. 3). The interaction of Chair Group by Visual Field did not differ between males and females ($F(1, 47) < 1$), nor between dextrals and sinistrals ($F(1, 47) = 1.58, p > .20$).

A separate ANOVA was performed on asymmetry scores for the free-vision facebook task with Gender, Handedness, and Chair Group as between-subjects factors. As predicted, the main effect of Chair Group was significant ($F(1, 47) = 5.93, p < .02$). This effect reflected the finding that Group LChair displayed a stronger leftward bias on the free-vision

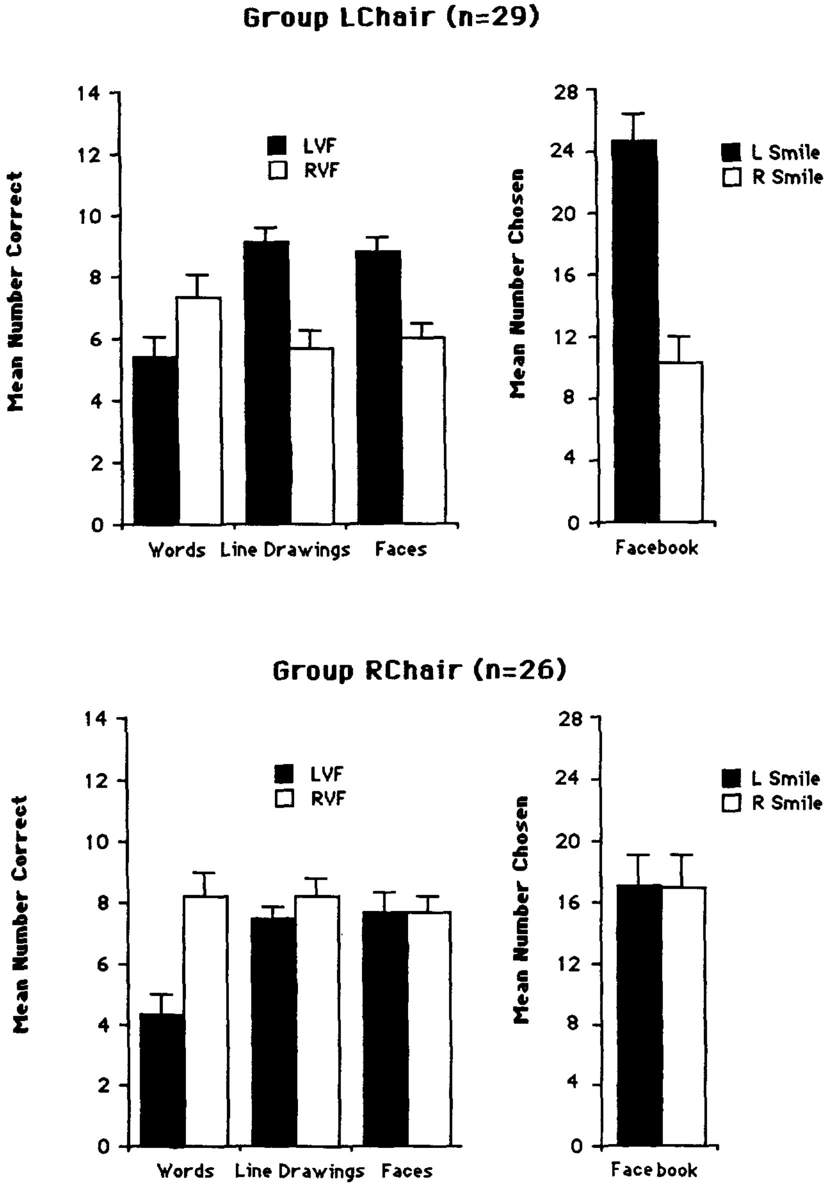

FIG. 3. Mean number of LVF and RVF correct responses for the tachistoscopic tasks and mean number of leftward and rightward responses for the free-vision facebook tasks for Group LChair and Group RChair.

task than Group RChair (see Fig. 3). Thus, subjects' asymmetry scores on the nonlateralized chair task consistently predicted their asymmetry scores on the tachistoscopic tasks as well as on the free-vision face task. The main effect of Chair Group did not differ between males and females ($F(1, 47) < 1$) or between dextrals and sinistrals ($F(1, 47) < 1$).

In order to investigate possible effects of report order biases on subjects' characteristic perceptual asymmetries on the tachistoscopic tasks, we coded subjects' order of responding on bilaterally correct trials for each tachistoscopic stimulus type. Each subject's report order bias was computed using the formula ($R–L$), where R is the number of bilaterally correct trials on which subjects reported from right to left, and L is the number of bilaterally correct trials on which subjects reported from left to right. Thus, a positive score indicated a right-to-left report order bias, and a negative score indicated a left-to-right report order bias. Analyses were performed using a nonparametric sign test (Ferguson, 1981) as bilaterally correct trials were relatively infrequent. A sign test for two correlated samples revealed that subjects as a whole had a strong left-to-right report order bias for tasks requiring verbal reports (words: $\chi^2 = 33.06$, $p < .001$; line drawings: $\chi^2 = 9.49$, $p < .01$), but not for tasks requiring recognition from arrays (chairs: $\chi^2 < 1$; faces: $\chi^2 < 1$). Of particular interest was the question of whether subjects in Groups LChair and RChair differ in their report order preferences. A sign test for two independent samples revealed that Group LChair and Group RChair did not statistically differ in report order biases for any of the tasks administered (words: $\chi^2 < 1$; chairs: $\chi^2 = 2.04$, $p > .10$; line drawings: $\chi^2 = 2.18$, $p > .10$; faces: $\chi^2 < 1$). Thus, differences in characteristic perceptual asymmetry in Groups LChair and RChair do not appear to be associated with differences in report order bias between subjects.

PCA of Laterality Tasks

A PCA was performed on subjects' asymmetry scores on the five laterality tasks. The result showed that two principal components had an eigenvalue greater than unity. These two components, combined together, accounted for 69.1% of the total variance in the sample (see Tables 1 & 2). We shall restrict our discussion of principal components to these two components. Components that have an eigenvalue less than unity explain less variance in the sample than an original variable. Moreover, these components may not be replicable with another sample, as they may reflect random variations specific to a particular sample (cf. Bernstein, Garbin, & Teng, 1987).

The first component was characterized by high and homogeneous loadings of all five tasks in the same direction. This component accounted for 45.2% of the total variance. A median-split of subjects based on this component indicated that the asymmetry scores of subjects with high

TABLE 1
CORRELATIONS BETWEEN ASYMMETRY SCORES

	Words	Chairs	Line drawings	Faces	Facebook
Words	X				
Chairs	.175	X			
Line drawings	.355**	.581**	X		
Faces	.246*	.259*	.146	X	
Facebook	.491**	.280*	.089	.522**	X

* $p < .05$.
** $p < .01$, one-tailed tests ($n = 63$).

PC1 scores were displaced toward the right on all five tasks relative to those of subjects with low PC1 scores (see Fig. 4). Emergence of this component is consistent with the hypothesis that subjects' asymmetry scores reflect individual differences in characteristic perceptual asymmetry. Correlational analyses revealed no relation between this component and either Handedness ($r(61) = .13$, $p > .20$) or Gender ($r(61) = .06$, $p > .60$).

The second principal component, which accounts for 23.9% of the total variance, was characterized by opposite loadings of the face tasks (tachistoscopic face recognition and the free-vision face task) and object recognition tasks (tachistoscopic chair and line drawing recognition). A median-split of subjects based on this component score revealed that subjects with high scores displayed a LVF advantage for the tachistoscopic face task, a leftward perceptual asymmetry for the free-vision face task, and a RVF advantage for the chair and line drawing tasks. In contrast, subjects with low scores displayed a LVF advantage for the chair and line drawing tasks and near zero asymmetries for both of the face recognition tasks (see Fig. 5). This component may reflect individual differences in hemispheric involvement in processing faces vs. nonfaces.

TABLE 2
PRINCIPAL COMPONENT ANALYSIS OF LATERALITY TASKS: ALL SUBJECTS

Tasks	PC1	PC2	PC3
Words	.451	−.157	−.750
Chairs	.450	.472	.371
Line drawings	.418	.610	−.139
Faces	.428	−.388	.528
Facebook	.483	−.477	.007
Eigenvalue	2.263	1.195	.801
Proportion of total variance	.452	.239	.160

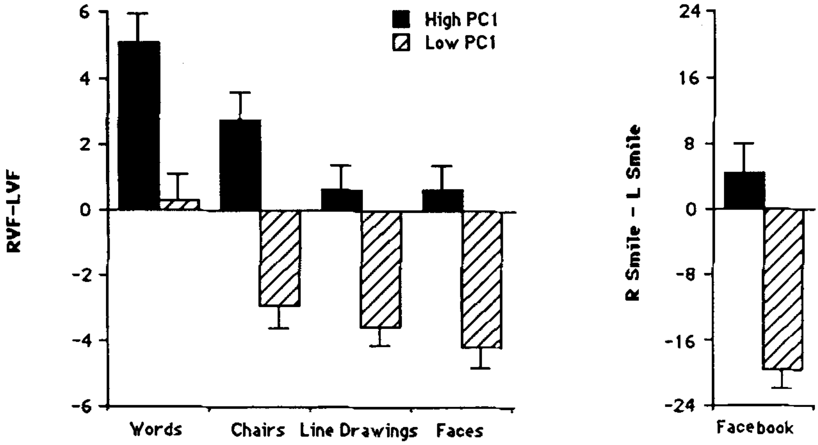

FIG. 4. Mean asymmetry scores for the tachistoscopic tasks (RVF–LVF) and facebook task (R Smile–L Smile) of high and low PC1 Groups as defined by a median-split on the principal component 1 scores.

As previously suggested (Diamond and Carey, 1986; Levine, 1989), the difference between processing of faces and other categories of objects may be due to different levels of expertise generally achieved for differentiating faces vs. other categories. Alternatively, this component may reflect individual differences in hemispheric involvement in processing emotional vs. nonemotional visuospatial stimuli, given that faces are affective stimuli as well as visuospatial stimuli (e.g., Ley & Bryden, 1979) (note also that for the free-vision facebook task, the task was

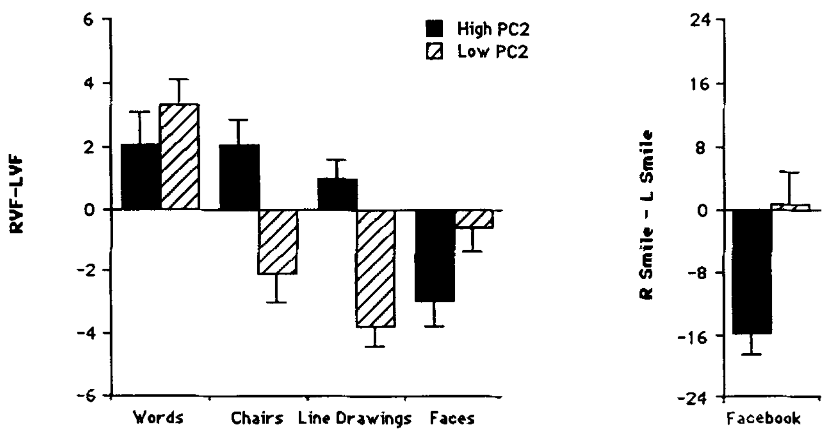

FIG. 5. Mean asymmetry scores for the tachistoscopic tasks (RVF–LVF) and facebook task (R Smile–L Smile) of high and low PC2 Groups as defined by a median-split on the principal component 2 scores.

TABLE 3
PRINCIPAL COMPONENT ANALYSIS OF LATERALITY TASKS: DEXTRALS, SINISTRALS, MALES, AND FEMALES

	Dextrals		Sinistrals	
Tasks	PC1	PC2	PC1	PC2
Words	.397	.408	.457	.239
Chairs	.430	−.070	.482	−.493
Line drawings	.369	.716	.481	−.514
Faces	.521	−.323	.352	.422
Facebook	.498	−.458	.448	.506
Eigenvalue	2.304	1.064	2.320	1.297
Proportion of total variance	.460	.212	.464	.259
	Males		Females	
Tasks	PC1	PC2	PC1	PC2
Words	.386	.622	.512	−.089
Chairs	.523	−.399	.350	.602
Line drawings	.369	−.502	.422	.530
Faces	.427	−.141	.473	−.411
Facebook	.506	.424	.460	−.423
Eigenvalue	2.437	1.098	2.374	1.469
Proportion of total variance	.487	.219	.474	.293

emotional evaluation of chimeric faces, i.e., "which face looks happier?"). In any case, inspection of asymmetry patterns in Fig. 5 suggests that when the processing of face stimuli is strongly lateralized to the right hemisphere, the processing of stimuli in other object categories is lateralized to the left hemisphere or bilateralized. Similarly, when processing of object stimuli is strongly lateralized to the right hemisphere, the processing of faces is bilateralized. As for the first component, correlational analyses revealed no relation between this component and either Handedness ($r(61) = .23$, $p > .05$) or Gender ($r(61) = .14$, $p > .20$).

Since it is possible that different subgroups may have different component structures, we also performed a separate PCA for the following subgroups of subjects: dextrals, sinistrals, males, and females (see Table 3). Some consistent patterns emerged, though the results of these analyses are preliminary due to the rather small number of subjects involved in each analysis (n = 30–33). In particular, in each analysis, the first component was extremely robust, reflecting the same pattern of task loadings found for the whole sample. That is, all laterality tasks loaded positively on this component. In addition, the amount of variance accounted for by this component was extremely consistent for the various handedness and gender groups, ranging from 46 to 48%. The loading patterns for the second component were more variable for these subgroups.[2]

MANOVA of Cognitive Tasks

A multivariate analysis of variance (MANOVA) was performed on the eight cognitive task scores with Gender and Handedness as factors. In this analysis, the only significant effect was a main effect of Gender (Wilk's $\lambda = .609$: $F(8, 52) = 4.17, p < .001$). Univariate F ratios indicated that males in our sample scored significantly higher than females on the Mental Rotations Test ($F(1, 59) = 14.36, p < .001$) and marginally significantly higher on the Verbal Analogy Test ($F(1, 59) = 3.75, p < .06$). Males and females did not differ significantly on the other cognitive tasks administered.

Relation between Asymmetry Scores and Cognitive Scores

In order to test whether individual differences in characteristic perceptual asymmetry predict performance on any of the cognitive tests in the current battery, correlational analyses were performed between the first component scores from the PCA and the eight cognitive test scores. None of these correlations was significant. Correlational analyses also were performed between the second principal component scores and the eight cognitive test scores. The only significant correlation was with Digit Span Forward ($r(61) = .274, p < .03$). The significant correlation may reflect a chance effect as eight correlations were simultaneously examined (If a composite p is protected at .05, each individual correlation should be considered significant at $p < .006$ [= .05/8]). In order to test whether the principal components from the PCA are related to discrepancy between verbal and spatial abilities, correlational analyses were performed between the principal components scores and [Verbal Analogy z score–Mental Rotation z score]. Neither the first nor the second principal

[2] It is well known that "rotation" of components allows infinite sets of mathematically equivalent ways to factor a matrix, a problem known as factor indeterminacy. We have reanalyzed our data using the varimax rotation method, the most commonly used rotation method. Results showed that two factors emerged, one factor on which words, faces, and facebook have high loadings and the other factor on which chairs and line drawings have high loadings. A general factor on which all variables have high loadings did not emerge by applying this method. This is not surprising, given that the general factor tends to be destroyed following varimax rotation, unless the data are overwhelmingly dominated by "g" (Bernstein, Garbin, & Teng, 1988). Given the a priori hypothesis concerning characteristic perceptual asymmetry, a PCA may be considered a more appropriate technique than rotated solutions, including the varimax solution (cf. Bernstein, Garbin, & Teng, 1988).

component scores were significantly correlated with variations in [Verbal Analogy z score–Mental Rotation z score] ($p > .50$ for each case).

DISCUSSION

Consistent with existing evidence that patterns of visual field asymmetry shift depending on the nature of the task presented (for a review, see Beaton, 1985), our results show a significant RVF (left hemisphere) advantage for recognizing words, a significant LVF (right hemisphere) advantage for recognizing faces and line drawings, and no visual field advantage for recognizing chairs. These findings support the hypothesis that patterns of hemispheric specialization are a major source of within-subjects variations in asymmetry scores.

In addition, our results provide support for the hypothesis that between-subjects variations in asymmetry scores reflect real individual differences in a task-independent perceptual asymmetry rather than random error in measurements. The evidence for this "characteristic perceptual asymmetry" comes from a number of sources. First, we found that the direction of subjects' asymmetry scores on the nonlateralized chair task predicts their asymmetry scores on left and right hemisphere specialized tasks. The findings that individuals' asymmetry scores on a task that is nonlateralized for subjects as a group are significantly correlated with their asymmetry scores on left and right hemisphere specialized tasks are consistent with the hypothesis that the nonlateralized task reflects differences in characteristic perceptual asymmetry rather than random fluctuations around zero. Second, using a PCA, we found that all tasks were weighted homogeneously in the same direction on the first principal component. This component accounted for almost half of the total variance (45.2%) in the sample. It does not seem possible to account for these findings if random error in measurement underlies all or nearly all of the variation among individuals' asymmetry scores. Thus, at least in part, the discrepancy between estimates of atypical asymmetry patterns in dextrals obtained from normal subjects and brain damaged patients may be due to laterality scores reflecting not only subjects' underlying pattern of hemispheric specialization but also their characteristic perceptual asymmetries (Kim & Levine, 1990a).

Our findings support the hypothesis that characteristic perceptual asymmetries are related to central factors such as hemispheric arousal asymmetry (Levy et al., 1983a). In particular, we found that the facebook task was positively correlated with the tachistoscopic tasks. It is unlikely that subjects' perceptual asymmetries on the facebook task which is presented in free vision reflect sensory pathway dominance. Thus, at least some of the variance accounted for by "characteristic perceptual asymmetry" must be attributable to central factors.

Of course, it could be argued that a systematic source of variance other than characteristic perceptual asymmetry accounts for the positive correlations among subjects' asymmetry scores on different laterality tasks. One possibility is that subjects have report order biases that influence their asymmetry scores on bilaterally presented tasks. That is, it might be the case that some subjects prefer to report from right to left whereas other subjects prefer to report from left to right. Given that subjects tend to more accurately report the first than the second item (Bryden, 1962), such a bias could lead to positive correlations among subjects' asymmetry scores on laterality tasks. Several findings, however, suggest that report order cannot fully account for variability among subjects' asymmetry scores. First, we examined the report orders of bilaterally correct trials of subjects in Groups LChair and RChair, and found no statistically significant differences. Second, we found that subjects' asymmetry scores on a task on which report order is irrelevant, the free-vision facebook task, are positively correlated with their asymmetry scores on the tachistoscopic tasks. Third, a significant positive correlation between subjects' asymmetry scores on left and right hemisphere specialized tasks (r = .54, Boles, 1989) also was found in a study that controlled for report order by requiring subjects to respond to the left member of a pair of bilaterally presented stimuli on half the trials and to the right member on the other half. Finally, it should be noted that even if consistencies in subjects' asymmetry scores across different tasks can be linked to report order biases and/or internal perceptual scanning biases, such biases may reflect underlying "characteristic perceptual asymmetries" (cf. Carr, 1969).

Our data further indicate that characteristic perceptual asymmetry does not differ significantly between males and females, or dextral and sinistrals. First, the interaction of Chair Group by Visual Field did not differ between males and females or between dextrals and sinistrals. Second, neither Gender nor Handedness is significantly related to the first principal component, the "characteristic perceptual asymmetry component" that emerged in the PCA analysis. In addition, the amount of variance accounted for by this component is similar between males and females (range: 47.4.7–48.7%) as well as between the two handedness groups (range: 46.0–46.4%). Thus, asymmetry differences that have been reported between males and females and between dextrals and sinistrals (e.g., Kimura, 1983b; McGlone, 1977, 1980; Rasmussen & Milner, 1975) do not appear to be related to group differences in characteristic perceptual asymmetry. In the present study, the "expected" asymmetry differences between dextrals and sinistrals, i.e., reduced asymmetry for sinistrals, were found only for recognition of faces. These findings might be partially due to the fact that a large proportion of the between-subjects variance in asymmetry scores, at least on tasks employing bilateral presentation of stimuli (Kim & Levine, 1990b,c), is attributable to characteristic perceptual asymmetry, a factor on which dextrals and sinistrals do not appear to differ.

Principal component analyses are less frequently applied to the analysis of laterality data than to the analysis of psychometric data (Hellige, 1990). However, it should be noted that asymmetry scores and intelligence test scores share certain characteristics. First, like intelligence test scores, asymmetry scores reflect many factors. In the case of asymmetry scores, these factors include, but are not limited to, characteristic perceptual asymmetry, hemispheric specialization, and strategy choices. Second, neither first-order correlations among cognitive measures nor first-order correlations among laterality measures are very informative about the relations among tasks. Similar to the influence of psychometric "g" on individuals' scores on diverse cognitive tasks, characteristic perceptual asymmetry mediates a general positive correlation among scores on diverse laterality tasks. This implies that underlying relations between laterality tasks may be more apparent once the characteristic perceptual asymmetry factor is partialed out. For example, in the current study, the contrasting relationships between asymmetry scores on face and object recognition tasks (Component 2) could be observed only after the characteristic perceptual asymmetry component is removed as the first principal component (see Table 2). In sum, like an intelligence test score, an asymmetry score can most readily be viewed as a composite of several individual traits. A PCA provides a quantitative means of decomposing the composite character of asymmetry scores. Thus, the application of PCA to laterality data may provide information not readily available through other statistical techniques.

The present study did not reveal any significant relationship between scores on the characteristic perceptual asymmetry component and performance on any of the eight cognitive tasks administered. Thus, the hypothesis that characteristic perceptual asymmetry in favor of RVF (assumed to reflect greater left hemisphere arousal) is associated with high verbal ability, whereas characteristic perceptual asymmetry in favor of LVF (assumed to reflect greater right hemisphere arousal) is associated with high spatial ability was not supported. It is possible that variations in characteristic perceptual asymmetry may have a greater effect on the allocation of attention in space and early cognitive processing stages than on the efficiency of complex cognitive operations. Alternatively, it is possible that some cognitive abilities not represented in our battery may be associated with individual variations in characteristic perceptual asymmetry.

Consistent with the absence of significant correlations, a recent review of the hemisphericity literature suggests that there is little evidence that cognitive task performance in the normal population is correlated with asymmetry on laterality tasks (Beaumont et al., 1984). Such findings have typically lead to the conclusion that individual differences in hemispheric specialization are not related to differences in cognitive abilities. In view of the current evidence that variations in asymmetry scores derive largely from individual differences in characteristic perceptual asymmetry, an alternative interpretation is that individual differences in characteristic perceptual asymmetry are not related to cognitive ability patterns.

Finally, it should be noted that although we found a positive correlation among subject' asymmetry scores on the laterality tasks included in our study, some previous studies have reported nonsignificant correlations among asymmetry scores (e.g., Bryden, 1973; Hellige et al., 1988). These differences may be due to the use of unilateral rather than bilateral tasks (note that the free-vision task used in the present study also presented different stimuli on each side of the stimulus midline). Studies of unilaterally brain damaged patients indicate that attention is markedly biased to the sensory half-field ipsilateral to the lesion, with concomitant "extinction" of stimuli presented to the sensory half-field contralateral to the lesion. This phenomenon is much stronger when stimuli are presented bilaterally than unilaterally and sometimes is only apparent when stimuli are presented bilaterally (for a review, see Bender, 1952; De Renzi, Gentilini, & Pattacini, 1984; Heilman & Watson, 1977). On the basis of these clinical findings, it is possible that characteristic perceptual asymmetry in normal subjects also will be manifested more consistently when stimuli are presented bilaterally rather than unilaterally. This hypothesis is supported by a study in our laboratory (Kim & Levine, 1990b) as well as by a meta-analysis of studies reported in the literature (Kim & Levine, 1990c).

On the basis of these find ngs, one might hypothesize that unilateral tasks provide a better measure of hemispheric specialization than bilateral tasks. However, this may not be the case. Although both bilateral and unilateral presentation methods may index hemispheric specialization, they both appear to index different, but significant, additional factors. For bilateral presentation, our studies suggest that "characteristic perceptual asymmetry" is another significant factor. For unilateral presentation, a study in our laboratory suggests that individuals' left and right sensory field scores are highly positively correlated (Kim & Levine, 1990b), suggesting that they are not independent. These findings suggest that individual subjects' patterns of hemispheric specialization cannot be indexed directly by any single bilateral or unilateral laterality task. However, it is possible that patterns of hemispheric specialization can be inferred by administering multiple laterality tasks to individual subjects (Kim & Levine, 1990a).

In sum, our results provide additional support for the influence of characteristic perceptual asymmetries on both dextrals' and sinistrals' asymmetry scores at least under conditions of bilateral input. Although the underlying mechanism of characteristic perceptual asymmetry is not known, it is clear that this source of individual difference accounts for a significant proportion of the between-subjects variance in asymmetry scores. It is important to separate this source of variation from underlying hemispheric specialization in order to investigate questions such as the relation between hemispheric asymmetries to cognitive abilities. Finally, the existence of such differences in characteristic perceptual asymmetry provides a possible explanation for the discrepancy between estimates of typical vs. atypical asymmetry patterns obtained from studies of brain damaged patients vs. normal adults (Kim & Levine, 1990a).

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