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CHOOSING SIDES: ON THE VARIABILITY OF LANGUAGE LATERALIZATION IN NORMAL SUBJECTS

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Abstract—We report test-retest reliabilities and individual asymmetries for a lateralized lexical decision task. Although acceptable reliability was found for word recognition, most subjects did not show statistically significant asymmetries, despite a robust right visual field group advantage. Intersubject variability was unrelated to sex, handedness, or familial sinistrality. We offer some suggestions as to why these differences are to be expected in the study of normal populations.

A GREAT deal of experimental inquiry in cerebral function has focused on the identification, assessment, and quantification of hemisphere differences in neurologically normal individuals. Given the intensity of research in this area, it would be reasonable to expect considerable stability of findings, such that new investigations have a firm base on which to proceed. This seems not to be the case. The measurement of hemisphere differences in normals has proven to be a much more complicated undertaking than earlier studies suggested.

Much of this complexity stems from extensive variability of data in this area. Although group lateralization effects usually (but not always) go in the expected direction, individual subjects display a remarkable versatility of response to laterally presented stimuli, such that individual performance is difficult to predict. This fact is often acknowledged in discussions of methodological issues [8].

Only a few studies have attempted to delineate the scope of individual variation in hemispheric asymmetries and the reliability of these intersubject differences. Test–retest reliability data for auditory asymmetries has been reported for several dichotic listening tasks [1, 3, 13, 14, 18, 24, 28, 30, 31, 33, 36, 38]. Correlations are typically significant and in the range of 0.50–0.80. However, the number of individuals showing a right-ear advantage (REA) is smaller than would be expected given the robust group effect reported [3, 18, 28, 36]. The dichotic listening results reported by BLUMSTEIN *et al.* [3] are representative. The test–retest reliability coefficient for $(R-L/R+L)$ ear advantages, with consonant-vowel stimuli, was 0.74. However, 15 of the 42 right-handed male subjects showed a left-ear advantage (LEA) in at least one session, and four of these had a LEA in both sessions. Overall, 29% of the subjects switched the direction of their ear advantages on retest.

Stability data for visual asymmetries has been published only for the report of letters projected to the right and left visual fields [13, 14, 24]. Test-retest correlations of (R-L) accuracy scores were extremely low: 0.1 for left-handed and 0.29 for right-handed [24]. Retest reliabilities for each separate visual field, across multiple sessions, produced a wide range of coefficients (right visual field (RVF): 0.3–0.91; left visual field (LVF): 0.003–0.86), with significant correlations appearing only after the second session. These results raise the possibility that visual hemispheric asymmetries are less stable than those obtained with auditory presentation. However, this is difficult to assess with data from only one visual task, as very poor reliability is also occasionally reported for some dichotic measures [36]. The possibility that subject variables such as handedness or sex may be involved in the stability of laterality effects [24] warrants further investigation.

In this paper, we report the performance shown by subjects making lexical decisions to laterally presented stimuli. We analyze these findings along two dimensions: the stability of subjects' lateral asymmetries on retest, and individual differences in the magnitude of observed asymmetry. The lexical decision task is a procedure which provides a relatively pure measure of access to the internal lexicon [10], uncontaminated by the effects of vocal speech production. This task has been used to investigate differential hemispheric asymmetries related to sex [4, 5], handedness [4, 5], word class effects [11, 12], encoding processes [2, 9], and attentional bias [19]. Failures to replicate some of these findings have also been reported [34, 35]. Test-retest reliabilities for these asymmetries have not been published, and the range of individual variation is unknown. We report such data below.

METHOD

Subjects

Twenty-six undergraduates (13 male, 13 female) served as subjects in two sessions, separated by a period of 1 week. All were native speakers of English with normal vision. Handedness was determined by a modified Edinburgh inventory [27]. Table 1 indicates the distribution of subjects according to handedness, familial sinistrality, and sex.

Stimuli

The stimuli consisted of five-letter strings, presented horizontally in upper case (Letraset 24-point Helvetica). The words were concrete, imageable, familiar nouns taken from the Toglia and Battig norms [37]. Nonwords were pronounceable letter combinations, following English orthographic constraints, and were not homophonic to actual English words. Three unique lists, each containing 50 words and 50 nonwords, were constructed from these stimuli. In each list half of the stimuli appeared in the right visual field and half in the left visual field. One list was used for practice trials, and the other two were used as experimental stimuli in separate sessions.

Stimuli were photographed and mounted on slides, positioned so that they were 2.5 degrees of visual angle from a central fixation point, and subtended 1.8 degrees of visual angle.

Apparatus and Procedure

Stimuli were backprojected to a screen 152 cm in front of the subject, using a Carousel projector with a Uniblitz shutter. Subjects were instructed to focus on a "+" projected in the center of the viewing screen. Eye fixation was monitored by a Gulf & Western eye movement monitor, which was interfaced to a PDP-11 computer used to control stimulus presentation and record responses. Before each trial the subject's eye position was determined. The stimulus was not presented if the subject was fixated more than 0.5 degrees of visual angle from the central marker. When the subject fixated in the defined area, a stimulus was shown randomly in the left or right visual field. Possible error of measurement with this system is 0.5 degrees.*

Subjects were instructed to make word/nonword decisions as quickly and accurately as possible, and to register their responses by pressing button switches, one held in each hand. The assignment of "word" response hand and list order was counterblanced within each handedness group.

*Although the error of our eye-movement monitoring equipment is 0.5 degrees of visual angle, stimuli were sufficiently removed from fixation (2.5 degrees of visual angle) to eliminate the possibility of bias in the results.

Table 1. Distribution of Subjects by Handedness, Familial Sinistrality (FS), and Sex

	Handedness					
	Right		Left		Ambidextrous	
	FS−	FS+	FS−	FS+	FS−	FS+
Males	3	2	3	4	1	0
Females	5	2	2	3	1	0
Total	8	4	5	7	2	0

Each session began with 100 practice trials presented in blocks of 20. At the beginning of the first session, stimulus exposure time was varied systematically between practice blocks to determine a threshold for each subject allowing approximately 75% correct responses. This stimulus duration was then used for the experimental trials in each session. Mean exposure time across subjects was 98 msec (range 45–145 msec). A brief rest period separated the practice set from the 100 test items, which were presented without interruption.

RESULTS

Overall visual field effects

Initial analyses of variance were performed to examine the effects of sex, handedness, family history of left-handedness, list, list order, and response hand used for "word" judgments. Only a sex × family history interaction reached significance (F (1, 16) = 7.60, $P < 0.05$, MSe = 11.94; $\eta^2 = 0.02$): males with no family history of left-handedness responded more accurately than males with a history of familial sinistrality. None of the above variables interacted with visual field.

A three-factor repeated-measures analysis of variance was then performed on visual field, session, and stimulus type (word/nonword) with accuracy of response as the dependent variable. Significant main effects were present for visual field, session and stimulus type. Responses were more accurate in the RVF (79.08%) than the LVF (65.35%) (F (1, 25) = 65.01, $P < 0.001$, MSe = 9.43, $\eta^2 = 0.15$), and correct responses were more frequent in the first session (73.88%) than in the second session (70.92%) (F (1, 25) = 6.25, $P < 0.05$, MSe = 3.45, $\eta^2 = 0.01$). Subjects made more accurate judgments about nonwords (76.88%) than about words (67.54%) (F (1, 25) = 7.92, $P < 0.01$, MSe = 35.84, $\eta^2 = 0.07$).

Two significant interactions were also found. A stimulus type × visual field interaction (F (1,25) = 14.92, $P < 0.01$, MSe = 31.97, $\eta^2 = 0.12$) indicated that subjects made significantly more accurate responses to words in the RVF than to words in the LVF. Means for nonwords in both visual fields did not differ significantly (see Figure 1). A second interaction of stimulus type × session (F (1, 25) = 9.90, $P < 0.01$, MSe = 7.59, $\eta^2 = 0.02$) reflected significantly larger mean differences between words and nonwords in Session II than in Session I.

The η^2 values indicate an acceptable amount of variance attributable to stimulus type (7%), visual field (15%), and the interaction of stimulus type and visual field (12%). Session and stimulus type × session together account for only 3% of the variance.

To determine whether the observed visual field differences are due to hemisphere differences in sensitivity, response criteria, or both, two-way ANOVAs (visual field × session) were performed with d' and log β as dependent measures. The former revealed a large RVF advantage in sensitivity (F (1, 25) = 20.42, $P < 0.001$, MSe = 0.28), accounting for 57% of the

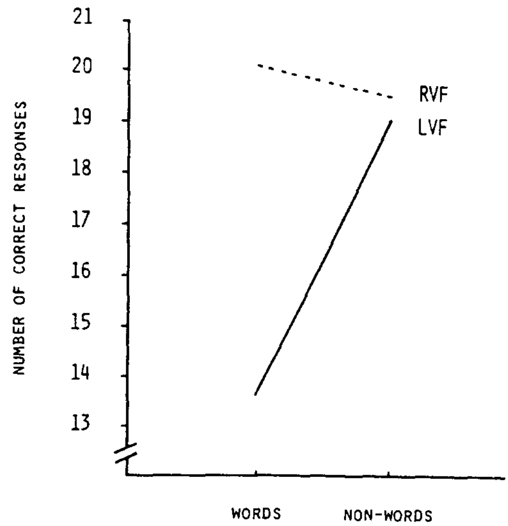

FIG. 1. Mean correct responses to words and nonwords in the right and left visual fields averaged over sessions. Maximum number correct = 25.

variance. This finding was constant across sessions, as revealed by the lack of significant findings for session and VF × session. Visual field differences in response criteria were also present (F (1, 25) = 5.13, $P < 0.05$, MSe = 0.11, $\eta^2 = 0.10$), with a slight bias towards word responses in the RVF (log $\beta = -0.06$), and nonword responses in the LVF (log $\beta = +0.08$). Subjects' response criteria became significantly more conservative in the second session (F (1, 25) = 13.12, $P < 0.01$, MSe = 0.03, $\eta^2 = 0.07$): a slight word bias occurred in the first session (log $\beta = -0.05$), but not in the second session (log $\beta = +0.07$). However, there was no interaction of VF and session in the log β measure, indicating that the relative VF differences in response bias did not change on retest.

Reaction time results paralleled those obtained with response accuracy: word decisions were faster in the RVF (658 msec) than the LVF (757 msec), while nonword responses did not differ across the visual fields (751 msec and 766 msec, respectively) (F (1, 25) = 8.81, $P < 0.01$, MSe = 10,555.58, $\eta^2 = 0.03$). This finding did not vary over sessions ($F < 1$). Since testing was conducted under near-threshold conditions, reaction times were not further analyzed.

Reliability

Several asymmetry indices were calculated on accuracy scores over both word and nonword trials: a d' laterality measure (d' RVF $- d'$LVF); a percent of difference index ($R - L/R + L$); and λ, a log odds ratio statistic introduced by BRYDEN and SPROTT [7]:

$$\lambda = \ln\left(\frac{(\mathrm{RVF}_{\mathrm{correct}} \times \mathrm{LVF}_{\mathrm{incorrect}})}{(\mathrm{RVF}_{\mathrm{incorrect}} \times \mathrm{LVF}_{\mathrm{correct}})}\right).$$

Test-retest coefficients for these indices reached an upper (non-significant) value of 0.27. An inspection of scatter plots for the data indicated that the low reliability was primarily due to an extreme restriction of the range of responses to nonwords. Consequently, we computed test-retest correlations separately on the number of correct responses to words and to nonwords. Word judgments reached acceptable levels of reliability in both the RVF ($r = 0.62$,

$P<0.001$) and the LVF ($r=0.78$, $P<0.0001$). Reliability coefficients for nonword responses were negligible in either visual field (rRVF$=0.36$, $P<0.04$; rLVF$=0.22$, ns).

Since acceptable levels of reliability were limited to word judgments, percent of difference and λ, indices were recalculated on word responses alone. It should be kept in mind, however, that these measures will reflect an asymmetry in both sensitivity and response bias. The percent of difference index showed a substantial degree of stability in hemispheric asymmetries across sessions ($r=0.81$, $P<0.0001$). The test-retest reliability coefficient for λ was somewhat lower ($r=0.69$, $P<0.001$). These two measures were highly intercorrelated ($r=0.83$, $P<0.001$).

Retest reliabilities were computed separately for males and females, left- and right-handed, and those with and without left-handed relatives. As shown in Table 2, these variables were not related to the stability of the visual field asymmetry.

Table 2. Retest reliabilities for sex, handedness, and family history of left-handedness

Sex	
Male	$r=0.68$
Female	$r=0.73$
Handedness	
Right-handed	$r=0.72$
Left-handed	$r=0.73$
Familial Sinistrality	
FS+	$r=0.72$
FS−	$r=0.68$

Individual asymmetries

As a final step in the analysis, we examined asymmetry scores for individual subjects. This analysis was restricted to word responses, nonword decisions being both unreliable and symmetrical across visual fields. To evaluate the statistical significance of each subject's asymmetry, z-scores (λ/S.E.) were computed, where the standard error is calculated as follows [7]:

$$\text{S.E.}=\sqrt{\frac{1}{\text{RVF}_{\text{correct}}}+\frac{1}{\text{RVF}_{\text{incorrect}}}+\frac{1}{\text{LVF}_{\text{correct}}}+\frac{1}{\text{LVF}_{\text{incorrect}}}}.$$

(Despite its higher reliability, we did not select the percent of difference index for this analysis because the arcsine transformation used to convert percentages to a normal distribution underestimates the standard error for percentages below 0.25 or above 0.75.) The λ standard score allows us to evaluate an individual's asymmetry against his own performance variability. Figure 2 displays this data for Sessions I and II, separately for male and female subjects. z-scores of $+1.96$ or greater indicate a significant RVF advantage, and those of -1.96 or less a significant LVF advantage ($P<0.05$).

As can be seen in Fig. 2, 50% of the scores revealed a significant visual field asymmetry. Only one individual had a significant LVF advantage. This subject was a left-handed male with no family history of left-handedness.

Six of the subjects (three right-handed, three left-handed) reversed the direction of their visual field asymmetry on retest. None of these individuals had a significant right visual field

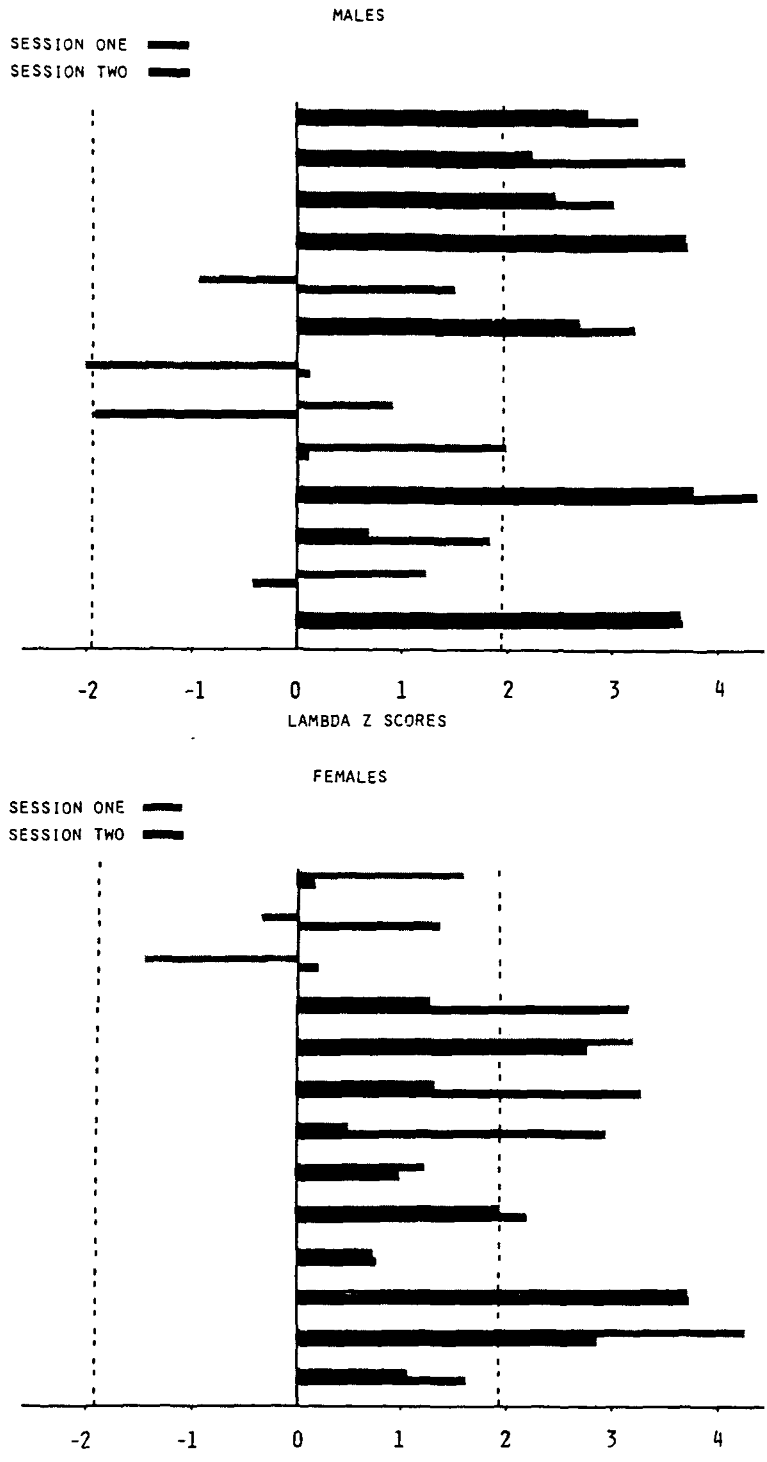

FIG. 2. z of λ for word responses in male and female subjects.

asymmetry in either session: five reliably showed no asymmetry, while one (the left-handed male mentioned above) had a significant LVF advantage only in the first session. In all, 10 subjects reliably showed no significant visual field differences. Only 11 subjects maintained a significant RVF advantage over both sessions. The composition of these two groups was equivalent in terms of sex, handedness, and familial sinistrality. It would appear that the overall statistically significant RVF effect actually reflects the stable performance of less than half (42%) of the subjects.

DISCUSSION

In general, reliability for lateralized word decisions is comparable to that reported for dichotic listening tasks. Significant test-retest correlations were obtained between two sessions, these being in the range reported for most dichotic measures. Contrary to the conclusions of previous studies [13, 14, 24], visual perceptual asymmetries are not necessarily less stable than auditory, even when the former do not involve bilateral simultaneous stimulation [25]. The strength of the test-retest reliability did not vary by sex, handedness, or familial sinistrality.

There is at least one important aspect of our results which was not addressed in previous reliability studies. We found divergent reliabilities and hemispheric asymmetries for two types of trials using the same subjects, performing the same task, under identical experimental conditions. Response to words were much more accurate in the right visual field, and word judgments were quite stable on retest within each visual field. In contrast, performance on nonword trials was equivalent across the visual fields and was also highly unreliable. Most lexical decision studies have reported the absence of laterality effects for nonword trials [4, 6, 26, 34, 35; but see also 2]. At present this is a reproduceable, although unexplained, finding. We add the information that nonword decisions, independent of visual field, are markedly unstable. Whether this instability is masking an underlying visual field difference for nonword judgments, remains an unanswered question.

The lexical decision performance we obtained (higher accuracy for nonword than for word responses) is compatible with a lexical access model incorporating a "deadline" for locating lexical entries [15, 16], rather than an exhaustive lexical search [29]. The equivalent performance across the visual fields for nonword decisions (both RT and accuracy) suggests that a similar deadline was employed in each visual field/hemisphere. If such were the case, asymmetries in lexical access efficiency would be manifested only for word decisions, a finding which we and other investigators [4, 6, 26, 34, 35] have obtained. Further speculation about mechanisms underlying lexical access in each hemisphere is beyond the scope of the present study, and must be premised on more reliable nonword performance than has thus far been obtained.

Although there is a clear RVF advantage in word identification ability, our results indicate that the group effects found in the analyses of variance conceal a considerable range of individual differences in lateral asymmetry. In addition, there is substantial intra-subject variation—23% of the subjects shifted the direction of their asymmetry on retest. This is a surprisingly recurrent figure. Nearly all investigators who have reported such data find 20-30% reversals [1, 3, 18, 28]. (SCHULMAN-GALAMBOS [31] reports a lower figure (10%) but only 10 subjects were tested.) Since the percent of asymmetry reversals remains constant across various studies, it cannot be attributed to differences in subject populations, stimulus modalities, experimental procedures or materials, or laterality statistics. It is evident from our data that these "unstable" individuals are likely to be those who did not originally show a significant (right) visual field advantage. BLUMSTEIN *et al.* [3] also reported that subjects with the smallest ear differences most often had reversed asymmetries on retest. It appears that the reliability of an individual's asymmetry is dependent on the strength of the laterality effect. Apparent "reversals" in the direction of a subject's lateral advantage are more likely an artifact of an insufficiently strong criterion for determining what constitutes a valid asymmetry. However, if we accept this reasoning, we must then conclude that true asymmetries are not present for over half of the subjects tested. By the customary convention of statistical significance, these subjects reliably showed no visual field difference. Further research is needed to determine whether this finding is specific to measures of receptive language.

Three interpretations can be considered for the range and stability of laterality effects observed in this task.

Measurement error

It is possible that our methods of assessing cerebral asymmetry are so noisy that substantial hemisphere differences will go undetected in many individuals. Under this interpretation, the majority of subjects would have a unilateral left hemisphere language substrate, with the observed discrepancies (persons with small RVF advantages, persons with LVF advantages, persons with no asymmetries) attributable to measurement error. Given the accumulated evidence of the effects of unilateral brain injury, this conservative approach seems compelling. However, if we are to adopt this position, we need to offer some suggestions as to where these errors of measurement are generated. It is evident that errors of measurement cannot be explained by such factors as stimulus modality, experimental procedures, response measures, or mathematical data treatments. These parameters have undergone almost infinite variation in the past two decades of lateralization research; yet nearly all studies of language processing can be said to produce an overall right field advantage, with wide variations in lateral asymmetry from person to person.

The data reported here also argue against measurement error as the prime cause of weak or unstable laterality effects. Every subject who achieved a statistically significant RVF advantage in the first session ($\lambda z > +1.95$), maintained this strong laterality on retest. Subjects who showed relatively weak lateralization in session I tended to show weak or reversed lateralization in session II. This leads us to suspect that the measurement instrument is relatively powerful, but that the phenomenon itself (cerebral lateralization) is not strongly manifested in most individuals, at least for this task. We do not deny that such data are subject to measurement errors. We merely question whether our assessments are indeed so primitive that they fail to detect a presumably strong left-hemisphere effect in such a large proportion of cases.

Hemisphere variation

A second possibility consistent with our data is that language lateralization is distributed in the population as a left hemisphere variate, with a range comparable to that found for measurable psychological phenomena, such as intelligence. If we take our data (shown in Fig. 2), and assume, as in an introductory statistics textbook example, that our sample is representative of true population values, we can apply the standard formulae for estimating the values of a population from a sample and derive a mean (+1.47) and standard error (1.26) for λ scores for the population of American college students. The accuracy of our estimates can be determined by comparison with other studies and our point estimates can stand until undermined by values obtained on larger samples.

Such an approach, a conservative cumulative estimate of population parameters, has much to recommend it. It is consistent with the view that there is a continuum or gradient of lateralization in the population [33]. Our analysis is an attempt to quantify this idea so that specific predictions about the distribution of lateral asymmetries in the normal population can be tested. This approach is worth pursuing and might well lead to a refinement in conceptions of hemisphere differences. At present, however, there is some evidence against the notion of stable individual differences in lateralization. Studies of cross-modal reliabilities have shown that a subject's degree of asymmetry on one task is a poor predictor of his lateral asymmetry as tested in another modality [13, 14, 25]. This should not be the case if individual differences in lateral performance simply reflect individual variations in the degree of hemispheric specialization. Similarly, behaviorally measurable variables as handedness do not consistently account for variability in hemispheric lateralization. Sex, handedness, and familial sinistrality were unrelated to individual performance in the present study.

Functional variation

Both interpretations offered thus far assume that cerebral lateralization itself is a stable entity, with observed fluctuations attributable to measurement error or individual differences. As a final possibility, we can consider the idea that cerebral lateralization is only a propensity in the normally functioning individual. The extent to which this predisposition is manifested in a subject's performance would depend on a host of factors which could be experimentally manipulated. A subject's "lateralization" may indeed change as a result of the nature and length of the task, other tasks being carried on simultaneously [c.f., 20, 22, 23], as well as some individual differences in the manner in which individuals react to these tasks. This position assumes that fluctuating lateral asymmetries reflect true variability in the phenomenon being measured rather than an instability in measurement.

There is evidence, both theoretical [17] and empirical [20, 22, 23, 32], that can support such an outlook. In FRIEDMAN and POLSON's [17] model, the hemispheres are viewed as independent resource centers. Variation in hemisphere performance can be introduced by task manipulations (which will alter the hemisphere-specific resources being demanded) as well as by intersubject differences (individuals differ in the extent to which hemisphere resources can be flexibly utilized for any particular task).

On the empirical level, SHANKWEILER and STUDDERT-KENNEDY [33] present some convincing evidence in support of the concept of a continuum of lateralization; HARDYCK *et al.* [20] have shown that lateralization effects can be manipulated through varying the frequency of trials relative to the number of stimuli used; and HELLIGE and his colleagues [22, 23] have demonstrated variations in lateral performance as a function of the alteration of concurrent memory loads. SCHWARTZ and KIRSNER [32] have recently shown that visual field differences for a letter matching task (1) differ for high and low verbal ability subjects and (2) can be manipulated by changing the proportion of name to physical matches presented within a visual field. Thus, the functional variation approach is consistent with our findings and those of many other investigators: aggregate laterality effects of a fairly robust sort, with wide variations in individual performance. To date, there is no experimental evidence to contradict this supposition, and it deserves serious consideration.

It is obvious that these three interpretations are not mutually exclusive. It seems reasonable to conclude that each of these factors contributes towards the characteristic variability in laterality effects among normally functioning individuals.

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