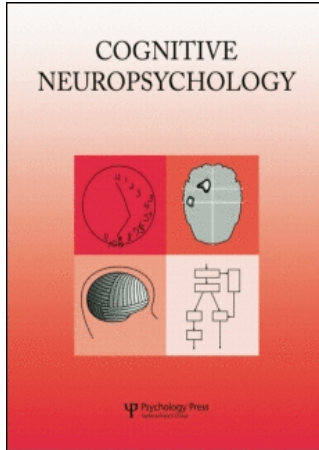


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Variance differences in asymmetry scores on bilateral versus unilateral tasks

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Variance Differences in Asymmetry Scores on Bilateral Versus Unilateral Tasks

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Kim and Levine (1991a) report that the correlations between subjects' asymmetry scores on left- and right-hemisphere specialised tasks are more positive when stimuli are presented bilaterally than when they are presented unilaterally (asymmetry scores computed as R-L for both tasks). This larger positive correlation may reflect the greater sensitivity of bilateral presentation to individual differences in non-stimulus-specific perceptual asymmetry, referred to in this paper as "characteristic perceptual asymmetry." If this is the case, variance in subjects' asymmetry scores on bilaterally presented tasks should be greater than on unilaterally presented tasks, reflecting the contribution of individual differences in characteristic perceptual asymmetry as an additional source of variance. The findings reported in this paper are consistent with this hypothesis. That is, a re-analysis of relevant data reported in the literature shows that for both visual and auditory laterality tasks, variance in asymmetry scores is significantly greater under conditions of bilateral than unilateral stimulation. Similarities between the differential effect of bilateral vs. unilateral stimulation in normal subjects and the clinical finding that "hemi-inattention" following unilateral brain damage is more readily observed with bilateral than unilateral stimulation are discussed.

INTRODUCTION

Perceptual asymmetries of normal right-handed subjects as indexed by laterality tasks (e.g. dichotic listening, lateralised tachistoscopic presentation) are extremely variable in both magnitude and direction. Although a number of studies have suggested that these variations reflect individual

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differences in underlying hemispheric specialisation (e.g. Boles, 1989; 1991; Kosslyn, 1987; Shankweiler & Studdert-Kennedy, 1975; Spellacy & Blumstein, 1970), clinical evidence indicates that patterns of hemispheric specialisation are extremely consistent among right-handed subjects. For example, sodium amytal testing carried out with patients who have intractable focal epilepsy indicates that about 95% of right-handed subjects have productive language functions lateralised to the left hemisphere (Rasmussen & Miller, 1975). In contrast, the proportion of normal right-handed subjects with "expected" right visual field-left hemisphere superiorities for processing verbal material is only about 70% (e.g. Kim & Levine, 1991b). It is possible that the discrepancy stems from the use of different tasks in studies of clinical and normal populations (e.g. production vs. comprehension language tasks). It is also possible that patterns of hemispheric specialisation in clinical patients are altered by adaptations to long-standing brain damage. Nonetheless, however, it is generally acknowledged that the wide discrepancy between asymmetry data obtained from normals vs. brain-damaged patients cannot be accounted for fully by wide variations in hemispheric specialisation among normal right-handed subjects.

Alternatively, some researchers have proposed that between-subjects variability in perceptual asymmetries reflect "random error in measurements" rather than real individual differences (Chiarello, Dronkers, & Hardyck, 1984; Colbourn, 1978; Satz, 1977; Schwartz & Kirsner, 1984; Teng, 1981). This proposal has been made, in part, in an attempt to explain the wide discrepancy between normal and clinical laterality data described earlier. Prior studies have also shown that the majority of laterality tasks have only low-to-moderate reliabilities (for a review, see Segalowitz, 1986), suggesting that a large proportion of between-subjects variability may, in fact, reflect random errors. However, some laterality tasks have been shown to be highly reliable (e.g. Levy, Heller, Banich, & Burton, 1983b; Wexler, Halwes, & Heninger, 1981), and even for these tasks, the magnitude and direction of subjects' asymmetry scores does not correspond well with the clinical data. For example, Wexler et al. (1981) report a test-retest reliability of 0.91 for their dichotic listening test, yet 23% of right-handed subjects in this study showed a reversed direction of asymmetry (computed from Fig. 1 in Wexler et al., 1981). Thus, the primary source of between-subjects variability on this task may not be random error in measurements or individual differences in hemispheric specialisation, but rather, some other stable individual trait(s).

Levy, Heller, Banich, and Burton (1983a) have proposed that such between-subjects variations reflect individual variation in "characteristic hemispheric arousal asymmetries." This characteristic arousal asymmetry results in perceptual asymmetry that is not stimulus specific, referred to in this paper as "characteristic perceptual asymmetry." According to Levy et

al.'s (1983a) hypothesis, the direction and degree of characteristic arousal asymmetry varies widely among normal right-handed subjects, ranging from strong asymmetries in favour of the left hemisphere, to nearly equal asymmetries, to strong asymmetries in favour of the right hemisphere. In contrast, patterns of hemispheric specialisation are posited to be extremely consistent among right-handed subjects. Thus, according to this hypothesis, both hemispheric specialisations and characteristic arousal asymmetry affect asymmetry scores, but individual variation in asymmetry scores around the group mean is largely attributable to individual variation in characteristic arousal asymmetry.

Levy et al.'s (1983a) hypothesis leads to the prediction that individual subjects will tend to maintain the same position relative to other subjects in the distribution of asymmetry scores on left-hemisphere specialised, right-hemisphere specialised, and non-lateralised tasks (Kim, Levine, & Kertesz, 1990) (see Fig. 1 for hypothetical results predicted by a strong version of this hypothesis). Consistent with this prediction, many studies reported a significant positive correlation between subjects' asymmetry scores on diverse laterality tasks (asymmetry scores computed as R-L for all tasks) (e.g. Boles, 1989; Bradshaw, Nettleton, & Taylor, 1981; Levine, Banich, & Koch-Weser, 1984; Levy et al., 1983a; Sidtis, 1984).¹ For example, Levy et al. (1983a) reported a positive correlation between subjects' asymmetry scores on left- and right-hemisphere specialised tasks. Similarly, Levine et al. (1984) reported that subjects' asymmetry scores on tasks that are non-lateralised for subjects as a group are positively correlated with their asymmetry scores for left- and right-hemisphere specialised tasks. Further, applying a Principal Component Analysis (PCA) to subjects' asymmetry scores on multiple laterality tasks, Kim, Levine, and Kertesz (1990) reported that as much as 50% of the total between-subjects variability in asymmetry scores may be accounted for by individual differences in characteristic perceptual asymmetry.

Central and/or peripheral factors may underlie individual differences in characteristic perceptual asymmetry. Levy et al. (1983a) suggest that hemispheric arousal asymmetry, a central factor, mediates characteristic per-

¹In some studies, the correlation between subjects' asymmetry scores on left- and right-hemisphere specialised tasks was not significant (e.g. Hellige, Bloch, & Taylor, 1988; Marcel & Rajan, 1975). Although these studies do not support the "characteristic perceptual asymmetry" hypothesis, these nonsignificant correlations should be interpreted cautiously. This is particularly true because most laterality tasks exhibit only low-to-moderate reliabilities (for a review, see Segalowitz, 1986). Thus, nonsignificant correlations between subjects' asymmetry scores on different laterality tasks may reflect attenuation caused by unreliability rather than a true dissociation. Consistent with this hypothesis, meta-analyses of the correlations between subjects' asymmetry scores on left- and right-hemisphere specialised tasks reported in the literature showed significant positive correlations in both visual and auditory modalities (Kim & Levine, 1991a).

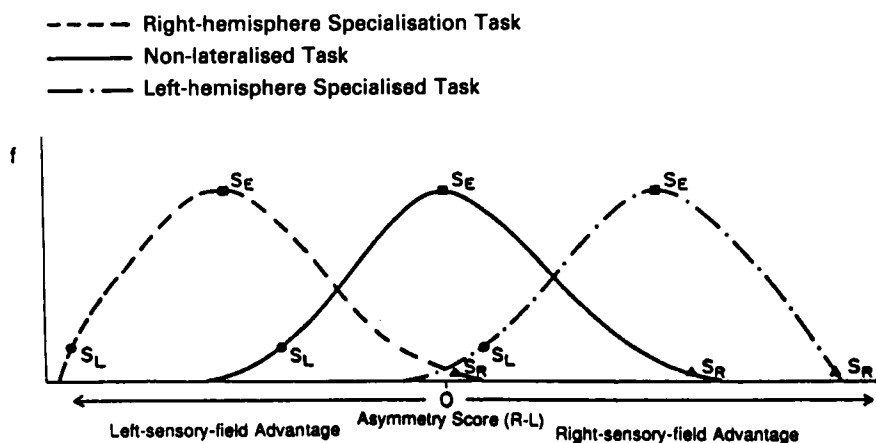


FIG. 1 Asymmetry scores predicted by a strong version of "characteristic perceptual asymmetry" hypothesis of a subject with characteristic perceptual asymmetry in favour of the right sensory field (S_R), a subject with nearly equal asymmetry (S_E) and a subject with characteristic perceptual asymmetry in favour of the left sensory field (S_L) on tasks for which the mean asymmetry score for the group is consistent with left-hemisphere specialisation, right-hemisphere specialisation or no significant difference between left- and right-hemisphere involvement.

ceptual asymmetry. According to this hypothesis, a subject's asymmetry scores on laterality tasks may be shifted to the left or right, in favour of the side of space contralateral to the more aroused hemisphere. Levy et al. (1983a) argue that the existence of stable individual differences in hemispheric arousal asymmetry among normal right-handed subjects is supported by a variety of types of evidence, 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 experimenter-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 0.88 for EEG asymmetry measures obtained on 11 normal right-handed subjects.

Some researchers have proposed that characteristic perceptual asymmetry may reflect a peripheral factor such as asymmetric sensory pathway strength (e.g. Efron, Koss, & Yund, 1983; Hellige, Bloch, & Taylor, 1988; Hellige & Wong, 1983; Lauter, 1982; 1983; Sidtis, 1982; 1984). For example, Sidtis (1982) suggests that there may be stable individual differences in the efficiency with which information is transmitted to the cortex

from the left vs. the right ear. Similarly, Hellige et al. (1988) raise the possibility that individuals may differ in the efficiency with which information is transmitted to the cortex from the left vs. the right visual field.

A number of considerations, however, suggest that variations in sensory pathway strength, even if they exist, may not fully account for individual differences in characteristic perceptual asymmetry. First, characteristic perceptual asymmetries are reflected by subjects' asymmetry scores on free-vision or free-field listening tasks as well as by their asymmetry scores on laterally presented tasks (for a review, see Kim & Levine, 1991a). For example, both Levy et al. (1983a) and Kim et al. (1990) found that there are significant positive correlations between subjects' asymmetry scores on a free-vision, face-processing task and their asymmetry scores on laterally presented tasks. The free-vision task does not involve lateralising input to one sensory field, and thus, characteristic perceptual asymmetries on this task cannot be attributed to sensory pathway dominance. Second, the correlations between subjects' asymmetry scores on left- and right-hemisphere specialised tasks are more positive when stimuli are presented bilaterally than when they are presented unilaterally (Kim & Levine, 1991a). This finding supports the hypothesis that bilateral stimulation is more sensitive to characteristic perceptual asymmetry than is unilateral stimulation. No such difference in sensitivity would be expected if characteristic perceptual asymmetry is solely mediated by perceptual factors such as sensory pathway dominance. Thus, characteristic perceptual asymmetry appears to be at least partially mediated by more central factors.

In the current study, we further investigate the hypothesis that bilateral stimulation is more sensitive to characteristic perceptual asymmetry than is unilateral stimulation (Kim & Levine, 1991a). According to this hypothesis, between-subjects variance in asymmetry scores on bilaterally presented tasks should be greater than on unilaterally presented tasks because of the contribution of individual differences in characteristic perceptual asymmetry as an additional source of variance. The current study tests this prediction by re-analysing relevant data obtained from studies reported in the literature. Although variance differences between subjects' asymmetry scores on bilateral vs. unilateral tasks have not been investigated systematically, some researchers have noted its presence (e.g. Boles, 1983; 1987). For example, Boles (1983) reports that on a word recognition task, the variance of subjects' asymmetry scores under conditions of bilateral stimulation is about two to four times greater than the variance of their asymmetry scores under conditions of unilateral stimulation. In a subsequent study, Boles (1987) found that the variance in subjects' asymmetry scores is greater with bilateral than unilateral stimulation for recognising bar graphs as well as words. However, the discussion of these findings focused on how the difference in these variances affects the testing of mean differ-

ences between the two stimulation conditions, and not on the question of what factors underlie the inequality of variances in the two presentation conditions.

METHODS

Data

Variances in asymmetry scores obtained under comparable conditions of bilateral and unilateral input were collected primarily from reviewing articles in the following journals: *Brain and Cognition*, *Brain and Language*, *Canadian Journal of Psychology*, *Cortex*, *Journal of Experimental Psychology: Human Perception and Performance*, and *Neuropsychologia*. The period of journal articles surveyed was from the mid-60s to 1990. Many potentially relevant studies could not be included in the review, as they did not report variances or related statistics. However, all studies that reported variances or related statistics were included in the review. This selection criterion should not bias our sample of studies in any systematic manner. In fact, none of the studies specifically addressed our hypothesis, i.e. whether variance of the subjects' asymmetry scores is greater under conditions of bilateral than unilateral presentation.

Twenty pairs of variances (one member of each pair from a bilaterally presented task, the other from a unilaterally presented task), drawn from 10 research articles, are included for analysis in this review. These variances are listed in Table 1 (visual studies) and Table 2 (auditory studies). For each study, the tables also include a description of the stimuli, the mean asymmetry scores in the bilateral and unilateral conditions, the statistical significance of the variance differences between bilateral and unilateral conditions, and a bibliographic reference. In three instances (Bryden, 1969; Dirks, 1964; McKeever, 1971) experimental conditions included one unilateral condition and two slightly different bilateral conditions (e.g. presence/absence of report-order control). In these instances, the variance in the unilateral condition was compared to the variance in each of the bilateral conditions.

Analyses

When variances were not directly reported in the studies, these values were recovered using the formula:

$$S^2 = N \frac{M^2}{t^2} \quad (1)$$

where S^2 is the variance, N is the number of subjects tested, M is the mean asymmetry score, and t is the t ratio used to test statistical significance of the mean asymmetry score.

When bilateral and unilateral tasks were given to different subjects, the variance differences were tested by the formula (Ferguson, 1981, p. 190):

$$F = \frac{S_b^2}{S_u^2} \quad (2)$$

where S_b^2 is the variance in the bilateral condition and S_u^2 is the variance in the unilateral condition. This occurred in 7 of 20 instances. In the remaining 13 instances, bilateral and unilateral tasks were given to the same subjects. In these cases, the variance differences were tested by the formula (Ferguson, 1981, p. 192):

$$t = \frac{(S_b^2 - S_u^2)\sqrt{N-2}}{\sqrt{4S_b^2S_u^2(1-r_{bu}^2)}} \quad (3)$$

where r_{bu} is the correlation between the paired asymmetry scores in the bilateral and unilateral conditions, and the other terms are as defined earlier. However, none of the studies with a within-subjects design included in our review reported r_{bu} . Thus, for the present purpose, we made the conservative assumption that $r_{bu} = 0$, which minimises the value of the test ratio t . For both (2) and (3), one-tailed probabilities are reported.

RESULTS AND DISCUSSION

Visual Studies

Sixteen pairs of s_b^2 and S_u^2 values were compared. Results are shown in Table 1. Consistent with the hypothesis that bilateral stimulation is more sensitive to characteristic perceptual asymmetry than unilateral stimulation, S_b^2 was greater than S_u^2 in all 16 instances. In 12 of the 16 instances, this difference was statistically significant ($P < 0.05$ in each instance) and in one additional instance (see Kim, Note 2), it was marginally significant ($P < 0.10$). In the other three instances (see Boles, 1983; McKeever, 1971; Olson, 1973), the difference was in the expected direction but was not statistically significant ($P > 0.10$). It should be noted that in two of the three nonsignificant instances, a within-subjects design was used. As explained in the Methods section, in these instances, the alternative to the null hypothesis (i.e. no significant difference in variance between unilateral and bilateral conditions) was conservatively tested.

In a previous review of studies reported in the literature, Kim and Levine (1991a) found that correlations between subjects' asymmetry scores on left- and right-hemisphere specialised tasks were more positive when stimuli were presented bilaterally than when they were presented unilaterally. This finding is consistent with the hypothesis that the additional variance obtained with bilateral stimulation reflects individual differences in characteristic perceptual asymmetry. However, a number of alternative

TABLE 1
Visual Studies

Study	Stimuli	S_b^2	M_b	S_u^2	M_u	P
Boles (1983)	Words	11.50 ²	10.00	11.00 ²	3.10	ns
Boles (1987)	Bargraphs (RT)	61.00 ²	44.00	30.00 ²	4.00	<0.05
	Letters (RT)	40.00 ²	-24.00	22.00 ²	-11.00	<0.05
	Words (RT)	60.00 ²	-19.00	27.00 ²	0.00	<0.05
Kershner & Jeng (1972)	Chinese	6.25 ²	9.05	1.73 ²	5.31	<0.05
	Words	7.94 ²	9.10	1.87 ²	5.91	<0.05
	Geometric forms	8.43 ²	1.80	1.40 ²	-6.14	<0.05
Kim (Note 2)	Words	4.95 ²	0.35	3.78 ²	2.00	<0.10
	Photos of chairs	2.87 ²	0.18	1.62 ²	-0.06	<0.05
	Photos of faces	2.62 ²	-4.88	1.64 ²	-1.34	<0.05
Liederman (1986)	Words	0.29 ²	0.27	0.13 ²	0.11	<0.05
McKeever (1971)	Words	5.40 ²	8.20	2.80 ²	6.40	<0.05
	Words	3.30 ²	5.10			ns
Olson (1973)	Words	5.00 ²	5.42	4.64 ²	3.42	ns
	Words	6.47 ²	6.20	4.57 ²	3.00	ns
Seitz & McKeever (1984)	Line Drawings (RT)	43.20 ²	-90.40	17.50 ²	-27.80	<0.05

Note: The units of measurement are the same as used in the original articles. The dependent variable is accuracy unless otherwise noted.

S_b^2 = the variance in asymmetry scores in the bilateral condition.

M_b = the mean asymmetry score in the bilateral condition.

S_u^2 = the variance in asymmetry scores in the unilateral condition.

M_u = the mean asymmetry score in the unilateral condition.

P = results of variance comparison between bilateral and unilateral conditions.

explanations for the greater variance obtained with bilateral than unilateral stimulation are considered.

One difference between bilateral and unilateral presentation is that many studies using bilateral input allow subjects to choose which of the two bilaterally presented stimuli to report first. No such choice, of course, is possible with unilateral input. This raises the possibility that the additional variance obtained with bilateral stimulation reflects individual differences in report-order biases (left-to-right vs. right-to-left). Of the reviewed studies, five instances involved a comparison of S_b^2 and S_u^2 where report-order in the bilateral condition was controlled by a directional arrowhead (< or >) at the fixation point (see Boles, 1987; Seitz & McKeever, 1984) or by requiring left-to-right report order for all trials (see McKeever, 1971). This allowed us to compare S_b^2 and S_u^2 without the contribution of free report-order for the bilateral condition. Inconsistent with the hypothesis that the additional variance obtained with bilateral stimulation reflects individual differences in report-order biases, S_b^2 was greater than S_u^2 in all

five instances in which report-order was controlled on the bilateral task. In four of the five instances, the difference was statistically significant ($P < 0.05$ in each instance), and in the other one, the difference was not significant ($P > 0.10$). In the nonsignificant instance (see McKeever, 1971), left-to-right report was required for all trials. Individual differences in characteristic perceptual asymmetry may not be as apparent with such a procedure because attention is biased to the left visual field for all subjects.

Another difference between bilateral and unilateral presentation is that subjects usually perform more accurately on unilateral than bilateral tasks because of the higher processing load typically present on bilateral tasks. If performance level in the unilateral condition is near ceiling, this would reduce variance in this condition relative to the bilateral condition. However, ceiling effects were not apparent in the unilateral condition in any of the studies reviewed, with the possible exception of Kershner and Jeng (1972). In this study, accuracy on the unilateral task was near 80%. Further evidence against the "accuracy level" explanation is provided by a study in which two stimuli were presented on each trial in both the bilateral and unilateral conditions (Liederman, 1986). Although subjects in this study actually performed slightly better in the bilateral than in the unilateral condition (28% vs. 25%), S_b^2 was significantly larger than S_u^2 ($P < 0.05$). Additional evidence against the "accuracy level" explanation comes from studies in which accuracy level was not relevant as RT was the dependent variable (see Boles, 1987; Seitz & McKeever, 1984). In all these studies, S_b^2 was significantly larger than S_u^2 ($P < 0.05$ in each instance).

Finally, bilateral presentation typically yields greater mean asymmetry scores than unilateral presentation.² This has been interpreted as evidence that bilateral stimulation is more sensitive to hemispheric specialisation than is unilateral stimulation (see Boles, 1990, for a review). Of the 16 instances included in the review, the bilateral mean asymmetry score was greater than the unilateral mean asymmetry score in 13 instances, and the reverse was true in the other 3 instances. Based on these results, it may be suggested that the additional variance obtained with bilateral stimulation is a "by-product" of subjects' greater mean on bilateral tasks. Inconsistent with this "by-product" explanation, however, is the finding that S_b^2 was greater than S_u^2 in all three instances in which the bilateral mean was smaller than the unilateral mean. In one of the three instances, the difference was statistically significant ($P < 0.05$), and in another, it was marginally significant ($P < 0.10$). In the third instance, the difference was not

²Note that when two levels of a between-subjects factor have unequal variances (i.e. violation of the homogeneity of variance assumption) the usual t (or F) test of the mean difference is biased. For proper testing of the mean difference with unequal variance, see, for example, Ferguson (1981, p. 182).

significant ($P > 0.10$). However, in the nonsignificant instance, left-to-right report order was required for all trials (see McKeever, 1971). As previously discussed, individual differences in characteristic perceptual asymmetry may not be as apparent under such conditions. Additional evidence against the "by-product" explanation comes from the two instances in which the mean asymmetry score in the bilateral condition was nonsignificantly greater than in the unilateral condition (see Kim, Note 2; McKeever, 1971). In both of these instances, S_b^2 was significantly greater than S_u^2 ($P < 0.05$ in each instance).

Auditory Studies

Four pairs of S_b^2 and S_u^2 values from dichotic and monaural listening tasks were compared. Results are shown in Table 2. Consistent with the visual studies, S_b^2 was greater than S_u^2 in all of these instances. In two of the four instances, the difference was statistically significant ($P < 0.05$ in each instance), and in the other two, it was marginally significant ($P < 0.10$). All four instances used a within-subjects design for which the presence of a variance difference was conservatively tested (see Methods). As for the visual studies, the additional variance obtained with dichotic (bilateral) stimulation may be attributable to individual differences in characteristic perceptual asymmetry. However, as for the visual studies, alternative explanations are considered.

First, we consider possible effects of report-order biases. Of the four pairs of dichotic-monaural variances included in the review, three instances involved a comparison of S_b^2 and S_u^2 in which report-order in the dichotic condition was controlled by cueing subjects as to which ear to report first (see Bryden, 1969; Dirks, 1964). In all of these instances, S_b^2 was greater

TABLE 2
Auditory Studies

Study	Stimuli	S_b^2	M_b	S_u^2	M_u	P
Bryden (1969)	Words	10.8 ²	7.2	7.2 ²	0.1	<0.10
		10.7 ²	6.8			<0.10
Dirks (1964)	Words	17.6 ²	4.4	10.8 ²	0.2	<0.05
		16.3 ²	7.0			<0.05

Note: The units of measurement are the same as used in the original articles. The dependent variable is accuracy.

S_b^2 = the variance in asymmetry scores in the dichotic condition.

M_b = the mean asymmetry score in the dichotic condition.

S_u^2 = the variance in asymmetry scores in the monaural condition.

M_b = the mean asymmetry score in the monaural condition.

P = results of variance comparison between bilateral and unilateral conditions.

than S_u^2 . In one of the three instances, the difference was statistically significant ($P < 0.05$), and in the other two, the difference was marginally significant ($P < 0.10$ in each instance). Thus, the additional variance obtained with dichotic stimulation does not appear to reflect individual differences in report-order biases. Second, ceiling effects were not apparent in the monaural condition in any of the studies reviewed. Further, the variance differences were no larger in the studies in which accuracy was closer to ceiling in the monaural condition (Bryden, 1969) than in the studies in which accuracy was farther from ceiling (Dirks, 1964). Thus, the greater variance with dichotic than monaural presentation does not appear to be related to accuracy differences in the two conditions. Finally, in all four instances, dichotic stimulation yielded both greater variance and greater mean asymmetry than monaural stimulation. Thus, we were not able to test whether the variance difference in the two presentation conditions is a "by-product" of the mean asymmetry difference in the two conditions.

GENERAL DISCUSSION

Interpretation of Greater Variance in Bilateral than Unilateral Conditions

In a previous review of the literature, Kim and Levine (1991a) reported that individual subjects' asymmetry scores on bilaterally presented tasks are more highly correlated with each other than are their asymmetry scores on unilaterally presented tasks. This was interpreted as reflecting the greater sensitivity of bilaterally presented tasks to non-stimulus-specific, characteristic perceptual asymmetry. Kim and Levine (1991a) proposed that this greater sensitivity of bilateral stimulation to characteristic perceptual asymmetry may be related to the varying demands that these two types of tasks make on subjects' processing resources. In particular, under conditions of competing bilateral input, in which processing resources are relatively limited, resources may be differentially allocated to the "characteristically" more aroused hemisphere. Thus, left-hemisphere aroused subjects may allocate more of their processing resources to the left hemisphere and right-hemisphere aroused subjects may allocate more of their processing resources to the right hemisphere. This would result in a wider distribution (greater variance) of subjects' asymmetry scores in the more demanding bilateral condition than in the less demanding unilateral condition.

The present review provides a further test of this hypothesis by investigating whether the variance of subjects' asymmetry scores is greater in bilateral than unilateral presentation conditions. It was reasoned that the

greater variability of subjects' asymmetry scores on bilaterally presented tasks would reflect the sensitivity of this type of stimulus presentation to individual variations in characteristic perceptual asymmetry. Our review indicates that for both visual and auditory laterality tasks, between-subjects variability in asymmetry scores is indeed greater when stimuli are presented bilaterally than when they are presented unilaterally.

In the Results section, consideration was given to several alternative explanations for the greater variance in subjects' asymmetry scores with bilateral stimulation besides the contribution of individual variation in characteristic perceptual asymmetry. These include the possibility that individual differences in report-order bias increase variance in the bilateral condition and the possibility that ceiling effects in accuracy reduce variance in the unilateral condition. As discussed, neither of these hypotheses appear to account for the finding of greater variance in the bilateral than the unilateral condition.

We also considered the possibility that the greater variance found under conditions of bilateral input reflects the greater sensitivity of bilateral stimulation to individual variations in hemispheric specialisation. This greater sensitivity to hemispheric specialisation has been hypothesised based on the finding that mean asymmetry scores under conditions of bilateral stimulation are generally greater than under conditions of unilateral presentation (Boles, 1990). However, arguing against the possibility that the greater variance in the bilateral condition reflects greater sensitivity to individual differences in hemispheric specialisation, variance in subjects' asymmetry scores was greater in bilateral than unilateral presentation conditions even when the mean asymmetry score in the bilateral condition was smaller than the mean asymmetry score in the unilateral condition.

Moreover, the results of previous studies seem more consistent with the explanation that the additional variance obtained with bilateral stimulation is attributable to individual differences in characteristic perceptual asymmetry rather than individual differences in hemispheric specialisation. In particular, the correlations between subjects' asymmetry scores on left- and right-hemisphere specialised tasks are more positive when stimuli are presented bilaterally than when stimuli are presented unilaterally (for a review, see Kim & Levine, 1991a). This finding is readily explainable in terms of higher sensitivity of bilateral stimulation to individual differences in non-stimulus-specific, characteristic perceptual asymmetry. However, it is not obvious how the hypothesis that the greater variance under conditions of bilateral stimulation reflects individual differences in hemispheric specialisation could explain this finding.

Finally, we consider the possibility that the greater variance obtained with bilateral stimulation reflects "random error in measurements." This hypothesis predicts lower reliabilities of asymmetry scores with bilateral

than unilateral stimulation. Boles (Note 1), however, shows reliabilities of asymmetry scores that are higher when stimuli are presented bilaterally than when they are presented unilaterally. Higher reliabilities of asymmetry scores with bilateral than unilateral presentation may reflect the fact that bilateral presentation is more sensitive to individual differences in characteristic perceptual asymmetry.

A further insight into the issue of reliability of asymmetry scores on bilaterally vs. unilaterally presented tasks comes from the fact that an asymmetry score is a difference score (Hines & Satz, 1974; Levy, 1983). According to a well-known formula for estimating the reliability of a difference score (e.g. Ferguson, 1981, p. 442), the reliability of an asymmetry (difference) score (r_{DD}) can be expressed as reliabilities of left and right sensory field scores (r_{LL} , r_{RR}) and the correlation between them (r_{LR}):

$$r_{DD} = \frac{r_{LL} + r_{RR} - 2r_{LR}}{2 - 2r_{LR}} \quad (4)$$

As noted by numerous psychometricians in more general contexts (see, e.g., Ferguson, 1981; Guilford, 1954; McNemar, 1969), for fixed values of r_{LL} and r_{RR} , reliability of asymmetry scores decreases, as the correlation between left and right sensory field scores (r_{LR}) increases in a positive direction. The correlation between left and right sensory field scores may reflect at least two factors: individual differences in the ability to process briefly presented information and individual differences in characteristic perceptual asymmetry. Individual differences in the ability to process briefly presented information would mediate a positive correlation between left and right sensory field scores, as "high ability" subjects perform well in both sensory fields whereas "low ability" subjects perform poorly in both sensory fields. In contrast, individual differences in characteristic perceptual asymmetry would mediate a negative correlation between left and right sensory field scores, as subjects who allocate more processing resources to the left hemisphere would process stimuli presented in the right sensory field well but stimuli presented in the left sensory field poorly. The reverse would be true for subjects who allocate more processing resources to the right hemisphere. Thus, higher sensitivity of bilateral than unilateral stimulation to characteristic perceptual asymmetry necessarily implies a less positive correlation between left and right sensory field scores with bilateral than with unilateral stimulation.³ Referring back to (4), this

³Note that the correlation between left and right sensory field scores (r_{LR}) is related to the variance of asymmetry scores (S_D^2):

$$S_D^2 = S_R^2 + S_L^2 - 2r_{LR}S_R S_L \quad \text{or} \quad r_{LR} = \frac{S_R^2 + S_L^2 - S_D^2}{2 S_R S_L}$$

where S_R^2 is the variance of right field sensory scores, and S_L^2 is the variance of left field sensory field scores.

means that bilateral stimulation should yield more reliable asymmetry scores than unilateral stimulation even when reliabilities of the sensory field scores are the same for the two types of tasks.

Though we are not aware of any studies in which r_{LR} of corresponding bilateral and unilateral tasks was investigated, the findings of Hines and Satz (1974) are highly supportive of the present hypothesis. This study shows high reliability ($r_{DD} = 0.86$) of subjects' asymmetry scores on a dichotic listening task involving recognition of digits, and much lower reliability ($r_{DD} = 0.46$) of the same subjects' asymmetry scores on a unilateral visual-field task involving recognition of digits. This difference was found despite the fact that both tasks yielded highly reliable sensory field scores (dichotic: $r_{LL} = 0.89$, $r_{RR} = 0.85$; unilateral visual: $r_{LL} = 0.92$, $r_{RR} = 0.91$). This pattern of results reflects a strongly negative r_{LR} for the dichotic listening task (-0.57) and a strongly positive r_{LR} for the unilateral visual field task (0.85). Presumably, this striking difference in r_{LR} and r_{DD} between the two tasks reflects the presentation method (bilateral vs. unilateral) rather than the presentation modality (auditory vs. visual) (Stone, 1980).

Parallels Between Characteristic Perceptual Asymmetry in Normal Subjects and Extinction to Simultaneous Stimulation in Brain-damaged Patients

A separate body of research carried out on unilaterally brain-damaged patients has shown that attention is markedly biased in favour of the hemispace ipsilateral to the lesioned hemisphere, with concomitant inattention to the side of space contralateral to the lesioned hemisphere (e.g. Bender, 1952; Heilman & Watson, 1977; Mesulam, 1981). Paralleling the present finding that characteristic perceptual asymmetry in normal subjects is more readily revealed by bilateral than unilateral stimulation, hemi-inattention following unilateral brain damage is more apparent under conditions of bilateral than unilateral stimulation, and sometimes is only apparent under conditions of bilateral stimulation (i.e. extinction to simultaneous stimulation; e.g. Bender, 1952; Heilman & Watson, 1977; Mesulam, 1981). This apparent similarity between characteristic perceptual asymmetry in normal subjects and extinction to double simultaneous stimulation in brain-damaged patients may stem from perceptual asymmetries in both populations reflecting an imbalance in hemispheric arousal, albeit a normal, smaller imbalance in one case and a larger, pathological imbalance in the other. Brain-damaged patients, like normal subjects, may allocate more processing resources to the intact, more aroused hemisphere under the more demanding bilateral condition (cf. Rapcsak, Watson, & Heilman,

1987; Riddoch & Humphreys, 1987). This would magnify arousal differences between the hemispheres, with the result that bilateral stimulation is more sensitive to hemi-inattention than is unilateral stimulation.

In normal subjects, the degree and direction of hemispheric arousal asymmetry may be a trait of each individual, whereas in brain-damaged patients, the imbalance may be determined primarily by characteristics of the lesion such as side, location, and size. Nonetheless, to some extent, a patient's premorbid arousal asymmetry may be reflected in the magnitude/direction of hemineglect shown following brain damage (Kim & Levine, 1991a; 1992). For example, following right-hemisphere damage, left-sided neglect may be stronger among subjects with characteristic perceptual asymmetry in favour of the right side of space (assumed to reflect greater left-hemisphere arousal) than among subjects with characteristic perceptual asymmetry in favour of the left side of space (assumed to reflect greater right-hemisphere arousal). The reverse would be expected following the left-hemisphere damage. That is, when the patient's characteristic arousal asymmetry biases attention to the side of space ipsilateral to the lesion, the tendency to neglect the contralateral field may be exaggerated. In contrast, when the patient's characteristic arousal asymmetry biases attention to the side of space contralateral to the lesion, the tendency to neglect the contralateral field may be attenuated. Studying extinction in unilaterally lesioned monkeys, Eidelberg and Schwartz (1971) similarly suggested that any post-operative changes in extinction should be evaluated relative to pre-operative lateralised biases.

There are further parallels between characteristic perceptual asymmetry in normal subjects and hemi-inattention in brain-damaged patients. Another key feature of hemi-inattention following unilateral brain damage is that it is more frequent and severe after right-hemisphere damage than after left-hemisphere damage (for a review, see Heilman & Watson, 1977; Mesulam, 1981). In addition, simple reaction time is increased more by right-hemisphere than by left-hemisphere damage (e.g. Benson & Barton, 1970; De Renzi & Faglioni, 1965; Howes & Boller, 1975). These findings suggest that the right hemisphere plays a more important role in regulating certain aspects of attention than does the left hemisphere (for a review, see Heilman & Watson, 1977; Mesulam, 1981). Paralleling the clinical finding that simple reaction time is increased more by right-hemisphere damage than by left-hemisphere damage, Wirsén, Klinteberg, Levander, and Schalling (1990) have found that normal subjects with leftward biases on a free-vision face-processing task (assumed to reflect greater right-hemisphere arousal) have faster simple reaction times than normal subjects with rightward biases (assumed to reflect greater left-hemisphere arousal). In addition, Levine, Yen, and Kim (Note 3) have found that subjects with characteristic perceptual asymmetry in favour of the right hemisphere have

shorter reaction times on Posner's valid-invalid trial task (1980) than have subjects with characteristic perceptual asymmetry in favour of the left hemisphere. These findings suggest that the right hemisphere plays a more important role in regulating certain aspects of attention than does the left hemisphere in normal subjects.

Finally, several recent studies have shown that patients with extinction to simultaneous stimulation in one modality often perform normally in the other modality (Barbieri & De Renzi, 1989; De Renzi, Gentilini, & Pattacini, 1984; Schwartz, Marhock, & Kreinick, 1988; Sieroff & Michel, 1987). For example, De Renzi et al. (1984) report that only 5 out of 43 patients (11.6%) with visual or auditory extinction show extinction in both modalities. Thus, extinction to double simultaneous stimulation is typically modality-specific rather than modality-general. Kim and Levine (1992) addressed the question of whether characteristic perceptual asymmetries among normal subjects are modality-specific or modality-general by performing a principal component analysis (PCA) on subjects' asymmetry scores on multiple bilateral visual field tasks and multiple dichotic listening tasks. Paralleling the clinical finding that extinction in brain-damaged patients is typically modality-specific, the PCA results showed that more of the variance in subjects' asymmetry scores is accounted for by a modality-specific component (36%) than by a modality-general component (21%). Thus, underlying hemispheric arousal asymmetry in both normal and brain-damaged populations may be typically modality-specific rather than modality-general.

In conclusion, information obtained from our review of the literature suggests that systematic sources of individual differences should be considered in the study of hemispheric asymmetries in normal subjects. It may be suggested that the unequal variance found between bilateral and unilateral conditions is a "methodological nuisance." From this point of view, the heterogeneity of variance should be eliminated by data transformation (e.g. log transformation) rather than be the subject of empirical investigation. However, because variance-equalising transformations are necessarily nonlinear transformations, the original and transformed variable cannot both be interval measures of the same theoretical construct (Bryk & Raudenbush, 1988). Thus, in order to justify a post-hoc transformation of asymmetry scores, it is necessary to show that the transformed score is a better measure of "hemispheric asymmetry" than is the original score. More importantly (Bryk & Raudenbush, 1988, p. 402), "the practice of routinely searching for data transformation that will eliminate heterogeneity (of variance) is misguided, because it could lead to a failure to recognise the substantive significance of heterogeneity." In the present review, the substantive significance of heterogeneity is self-evident in that it is present in nearly all reviewed studies.

Recently there has been much debate in the neuropsychological literature about the utility of single case vs. group studies of brain-damaged patients (e.g. Caplan, 1988; Caramazza, 1986; Caramazza & McCloskey, 1988; Whitaker & Slotnick, 1988). Analyses of individual differences vs. analysis of mean differences in normal subjects is roughly comparable to the case study vs. group study approach in clinical investigations. Historically, there have been two traditions in psychology—one that has the goal of characterising the “modal” human being and the other that has the goal of characterising individual differences (Cronbach, 1957).⁴ In the former tradition, individual differences have often been viewed (Bryk & Raudenbush, 1988, p. 396) “as a methodological nuisance or an unwelcome obstacle in the pursuit of inferences about the effects of treatments on means.” The present study shows that theoretically important results on individual differences can be missed if research methodology focuses exclusively on mean differences (Bryk & Raudenbush, 1988).

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