BRAIN AND COGNITION 3, 317–334 (1984)

Variations in Patterns of Lateral Asymmetry among Dextrals

SUSAN COHEN LEVINE, MARIE T. BANICH, AND MARGARET KOCH-WESER

Departments of Pediatrics and Behavioral Sciences, University of Chicago

Evidence supporting individual variations in patterns of hemispheric involvement in the recognition of visuo-spatial and verbal stimuli among dextrals is reported. In Experiment 1, subjects' asymmetry scores on a task that was nonlateralized for the group as a whole were significantly correlated with their asymmetry scores on right-hemisphere-specialized tasks, including face recognition. In Experiment 2, subjects' asymmetry scores on a task that was nonlateralized for the group as a whole were significantly correlated with their asymmetry scores on a left-hemisphere-specialized word recognition task. These results suggest that individual dextrals' asymmetry scores on lateralized tasks are a joint function of a subject's underlying hemispheric specialization for that task and stable individual variations in asymmetric hemispheric reliance.

Studies of hemispheric specialization employing standard laterality techniques (e.g., dichotic listening, tachistoscopic presentation) generally report that only about 70% of dextrals show the "expected" left-hemisphere superiority for processing verbal materials and right-hemisphere superiority for processing visuo-spatial stimuli and musical stimuli. Until recently, the possibility that variations in laterality patterns among dextrals reflect characteristic individual differences in hemispheric utilization for cognitive functions other than speech (Rasmussen & Milner, 1977) has not been the subject of systematic empirical investigation. Typically, variations in laterality patterns among dextrals have been attributed to random error in the measurements used (Teng, 1981) or to noise introduced by subjects' perceptual biases [e.g., directional scanning preferences induced by reading habits (Levine & Banich, 1982; White, 1969)]. Neither of these explanations, however, adequately accounts for the large variations in the direction and degree of lateral asymmetries observed for dextrals on verbal and spatial tasks.

The present study consists of two experiments designed to investigate

We are grateful to the Benton Educational Fund for support of this research. We also thank Jerre Levy for helpful comments and suggestions. Requests for reprints should be sent to Susan Cohen Levine, Department of Pediatrics, University of Chicago, 950 East 59th Street, Chicago, IL 60637.

0278-2626/84 $3.00

the stability of dextrals' laterality patterns across different tasks. The finding of consistent laterality patterns within individuals would rule out explanations that the heterogeneity in laterality patterns found across dextrals is attributable to random error in the measurements typically used to investigate hemispheric asymmetries in normals, e.g., tachistoscopic and dichotic listening tasks.

A second purpose of the present study is to determine whether subjects' asymmetry scores on tasks that are lateralized for the group of dextrals as a whole are highly correlated with their asymmetry scores on tasks that are nonlateralized for the group of dextrals as a whole. It is possible that individual differences in asymmetry scores on tasks that are non-lateralized for the group as a whole reflect random fluctuations around zero. Alternatively, the finding of a significant relation between asymmetry scores on nonlateralized and lateralized tasks would suggest that individuals' asymmetry scores on the nonlateralized tasks are indexing individual variations in asymmetric hemispheric reliance. Of particular interest is the question of whether subjects with a right-hemisphere bias on a non-lateralized task show a larger right-hemisphere advantage on a visuo-perceptual task such as face recognition than subjects with a left-hemisphere bias on a nonlateralized task (Experiment 1). Similarly, in Experiment 2, the question of whether subjects with a left-hemisphere bias on a nonlateralized task show a larger left-hemisphere advantage on a word recognition task is investigated. Such a pattern of findings would suggest that individual dextrals' asymmetry scores on lateralized tasks are a joint function of task demands and individual variations in asymmetric hemispheric reliance.

Such a pattern of results would also be consistent with recent findings of consistent patterns of lateral asymmetry across different tasks among individual dextrals. Burton and Levy (1984) found a high correlation between subjects' laterality scores on a free-vision face processing task involving judgment of emotional intensity and their laterality scores on a tachistoscopic face recognition task involving matching faces across orientation transformations. This finding supports the existence of consistent individual variations among dextrals in hemispheric involvement in face processing tasks. In another study, Levy, Heller, Banich, and Burton (1983) found that a greater right visual field (RVF) asymmetry on tachistoscopic recognition of nonsense syllables was correlated with a decreased left visual field (LVF) asymmetry on the free-vision face task. The results of this study suggest that certain right-handed individuals rely more on right-hemisphere processing for verbal as well as spatial tasks. Levy et al. (1983) interpret the results of these studies as support for stable individual variations in arousal asymmetry of the hemispheres. They posit that a subject's asymmetry score on a lateralized task reflects both hemispheric specialization for that task, which is more or less invariant among dextrals, and characteristic hemispheric arousal asymmetry, which varies among dextrals. Evidence from a variety of sources supporting the existence of variations in hemispheric arousal asymmetries among dextrals is reviewed; e.g., measurement of EEG asymmetries (Furst, 1976; Ray, Newcombe, Semon, & Cole, 1981), measurement of cerebral blood flow asymmetries (Dabbs, 1980; Dabbs & Choo, 1980; Gur & Reivich, 1980), and measurement of the direction of conjugate lateral eye movements in response to reflective questions (Bakan, 1969; Gur, Gur, & Harris, 1975; Sackeim, Packer, & Gur, 1977). This literature suggests that hemispheric arousal asymmetries are relatively characteristic of individuals as they are related to a variety of cognitive and personality measures (Gur & Gur, 1975; Gur & Reivich, 1980). [See Levy et al. (1983) for an extensive review of this literature.]

In addition to investigating the relation among dextrals' lateral asymmetries for the recognition of different stimulus types, the present study investigates the relation of asymmetry to overall performance level for each stimulus type. Existing evidence suggests that characteristic hemispheric arousal asymmetry in favor of one hemisphere (as measured by EEG or regional cerebral blood flow) is associated with better performance on tasks for which that hemisphere is specialized (Dabbs, 1980; Dabbs & Choo, 1980; Furst, 1976; Gur & Reivich, 1980). For example, Gur and Reivich (1980) report that performance on the Gestalt Completion Test (Ekstrom, French, Harman, & Dermen, 1976) is positively correlated with degree of asymmetric right-hemisphere blood flow. In agreement with these findings, results of several recent tachistoscopic studies report significant positive correlations between performance level and degree of visual field asymmetry on taks for which the contralateral hemisphere is specialized (Burton & Levy, manuscript in preparation; Ladavas, Umiltà, & Ricci-Bitti, 1980).

EXPERIMENT 1

Experiment 1 of the present study investigates individual variations among dextrals' lateral asymmetries for the recognition of four different classes of visuo-spatial stimuli: faces, cars, houses, and chairs. A LVF advantage is predicted for the face recognition task on the basis of an abundance of evidence from studies of unilaterally brain-damaged patients (e.g., Benton & Van Allen, 1968; Milner, 1960, 1968; Warrington & James, 1967), commissurotomy patients (e.g., Levy, Trevarthen, & Sperry, 1972), and normal adults (e.g., Levine & Koch-Weser, 1982; Rizzolatti, Umiltà, & Berlucchi, 1971), supporting differential right-hemisphere involvement in the recognition of faces. In fact, there is reason to believe that the right hemisphere is more involved in face recognition than in the recognition of other complex visuo-spatial stimuli (Leehey, Carey, Diamond, & Cahn, 1978; St. John, 1981; Yin, 1969). The general finding of differential right-hemisphere involvement in visuo-spatial tasks (e.g., DeRenzi & Spinnler, 1966; Levy, 1969; Milner, 1974; Teuber, 1974) suggests that significant asymmetries in favor of the LVF will be obtained for the recognition of the other simulus types as well, with the possible exception of chairs; subjects may show no visual field asymmetry on the chair recognition task, as DeRenzi and Spinnler (1966) found no significant difference between the ability of left- and right-brain-damaged patients to recognize chairs.

The hypothesis that individual dextrals show characteristic patterns of hemispheric involvement in cognitive tasks would be supported by the finding of a significant positive correlation among subjects' asymmetry scores for the four stimulus types. Further, if the chair recognition task is nonlateralized for dextrals as a group, suggesting that the specialized processes of one hemisphere are no more involved than the specialized processes of the other, it might serve as an indicator of individual variations in characteristic hemispheric involvement in cognitive tasks. That is, better recognition of chairs in the RVF may indicate asymmetric hemispheric reliance in favor of the left hemisphere and better recognition of chairs in the LVF may indicate asymmetric hemispheric reliance in favor of the right hemisphere. Thus, subjects with a LVF advantage for the recognition of chairs may show a larger LVF advantage for the recognition of faces, and possibly houses and cars as well, then subjects with a RVF advantage for the recognition of chairs.

Methods

Subjects

Twleve male and twelve female subjects consisting of University of Chicago students and staff were tested. All were right-handed with right-handed parents and had normal or fully corrected vision according to self-report.

Stimuli and Apparatus

Stimuli were bilaterally presented to binocular view in a Gerbrands two-channel tachistoscope (Model T-2B1). The stimuli consisted of black and white front-view photographs of faces, cars, chairs, and houses, with 24 examples from each category. The face stimuli were unfamiliar to subjects and consisted of adult male and female faces with neutral expressions.

For each class of stimuli, two choice arrays of 12 pictures were formed. An attempt was made to place items of similar brightness in the same array, e.g., lighter-toned chairs in one array, darker-toned in the other. For the faces, one array contained all females, the other all males.

From each choice array, nine bilateral stimulus pairs were constructed using eight pictures twice, two once, and two never, in order to discourage a "process of elimination" strategy for picture pairs shown late in the series. When a picture was repeated, it appeared with a different picture and in the opposite visual field than on its first presentation. Both members of a stimulus pair appeared in the same array. On each stimulus card, the near point of each picture was located 1°42′ to the left or right of fixation and each picture subtended 3°24′ of horizontal visual angle. Vertical visual angle ranged from 2°43′ for cars to 4°5′ for faces. A digit ranging from 2 to 9 was chosen at random to appear at the fixation point of each card. The digit provided control over fixation, since data from trials on which the digit was reported incorrectly were excluded.[1] (The digit was reported incorrectly on only 2.1% of all the trials administered.)

Procedure

Subjects began each trial by viewing a preexposure field consisting of six lines radiating from an open space at the center of the field. The space was just large enough to be filled by the fixation-point digit on each stimulus card. Two trials with cards having only a digit at the fixation point were shown in order to accustom subjects to the procedure. Eight practice trials preceded presentation of each block of pictures. Prior to each trial, the experimenter said "Focus" to alert the subject to fixate on the center space. The stimulus card was then flashed, followed immediately by the return of the preexposure field. On each trial, the subject first reported the center digit and then made a forced choice of two pictures from the appropriate array, which was presented by the experimenter. Subjects were informed in the instructions that not all pictures in the array would be presented and that some would be repeated.

Pictures were blocked by type (faces, cars, houses, chairs) and four orders of presentation of the picture-type blocks were counterbalanced across subjects. Within each block of pictures, one fixed random order was used for all subjects. Side of presentation of the two members of each pair was counterbalanced across subjects. In an attempt to equate overall performance level for the four picture types, different exposure durations, chosen on the basis of pilot work, were used for each picture type: 90 msec for faces, 200 msec for cars, 25 msec for chairs, and 130 msec for houses.

Results

A one-way analysis of variance on the visual field difference scores for each stimulus type was performed.[2] The counterbalancing factors of

[1] Requiring report of a central digit to monitor fixation is a widely used technique. While some investigators report that this technique does not affect results of laterality studies (MacKavey, Curcio, & Rosen, 1975; McKeever, Suberi, & Van Deventer, 1972; Hines, 1978; Duda & Kirby, 1980), others report that it activates the left hemisphere (Carter & Kinsbourne, 1979; Mancuso, Lawrence, Hintze, & White, 1979). In our laboratory, we have consistently found LVF advantages for the recognition of visuo-spatial stimuli (e.g., faces) using central digit report. Thus, any possible left-hemisphere activation resulting from the use of this technique must be small. In addition, since central digit report was used for all stimulus types in the present study it could not account for the overall pattern of results obtained.

[2] When accuracy of performance in each visual field is of interest, analyses are frequently performed using LVF and RVF performance levels as the basic data instead of, or in addition to, LVF − RVF difference scores. It has been typical, if not universal practice, to calculate the proportion of correct responses in the LVF by pooling over unilateral correct LVF responses (L) and bilateral correct responses (B), and to calculate the proportion of correct RVF responses by pooling over unilateral correct RVF responses (R) and bilateral correct responses (B). Levy (personal communication) suggests that this practice is problematic since it assumes independence of responses on a single bilateral correct trial. In the present study, to provide a complete view of the data, mean number of unilateral left (L), unilateral right (R), and bilateral correct responses (B) are reported for each stimulus type (see figures). Of note is the finding that in the present study, the frequency of bilateral correct

Sex and Presentation Order were not included in this analysis since a preliminary analysis revealed that neither the main effects nor interactions involving these factors were significant. The main effect of Stimulus Type was significant ($F(3, 92) = 2.86, p < .05$). The LVF − RVF difference scores were significantly greater than zero for faces ($t(22) = 3.89, p < .001$), houses ($t(22) = 2.68, p < .01$), and cars ($t(22) = 3.26, p < .025$), but not for chairs, which were recognized equally well in the LVF and RVF. Moreover, consistent with DeRenzi and Spinnler's (1966) finding of no difference between the ability of left- and right-brain-damaged patients to recognize chairs, the asymmetry score for the chairs differed significantly from the asymmetry scores for all the other stimulus types ($p < .008$).

Although the absolute asymmetry for faces is larger than that for houses and cars, post hoc tests show that it is not significantly larger ($p > .10$). It should be noted that 79% of subjects showed a LVF advantage for faces, 67% for houses and cars, and 58% for chairs. The absence of an asymmetry for chairs raises the question of how the recognition of this stimulus type differs from the recognition of the other stimulus types tested. One could speculate that the recognition of chairs is based on salient isolated features while the recognition of the other stimulus types is based on more configurational information, given what is known about the nature of the specialized processes of the right cerebral hemisphere (e.g., Leehey et al., 1978; Yin, 1969). It should be noted that subjects recognized chairs at a level comparable to the other stimulus types (see Fig. 1). However, for chairs, subjects required only 25 msec to reach this level of performance, while for the other stimulus types they required at least 90 msec. This suggests that chairs were recognized on the basis of different types of information than the other stimuli. It is possible that nonlateralized stimulus types tend to be recognized more quickly than lateralized stimuli. This possibility is supported by Experiment 2 of the present study, in which line drawings, the nonlateralized stimulus type, were recognized significantly better than corresponding words, the lateralized stimulus type, even though line drawings were shown for an average exposure duration of 23 msec vs. 79 msec for words (see Levine

---

responses is small relative to the frequency of unilateral correct responses. Further, in the present study, the frequency of bilateral correct responses is significantly correlated with performance level on unilaterally correct trials (L + R), but is not significantly correlated with asymmetry (L − R) for faces, houses, or chairs. For car recognition, relatively few bilateral correct responses were made, and B correlated neither with L − R nor with L + R. It should be noted that summing over unilateral and bilateral correct trials in deriving LVF and RVF scores is not likely to affect the finding of significant visual field asymmetries, particularly when the proportion of bilateral correct responses is small relative to the proportion of unilateral correct responses.

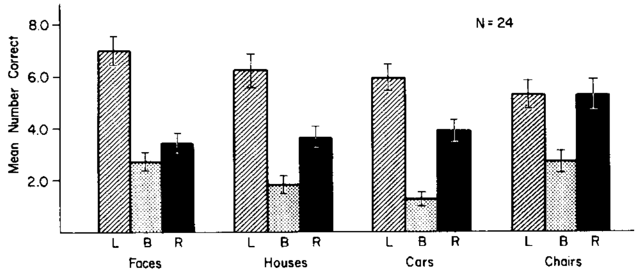

FIG. 1. Mean number of trials on which unilateral correct responses were made in the LVF (L), unilateral correct responses were made in the RVF (R), and bilateral correct responses (B) were made for faces, houses, cars, and chairs, across all subjects. On all figures, standard errors were calculated separately for L, B, and R for each stimulus type.

& Banich, 1982). Thus, an absence of a visual field asymmetry for a particular class of stimuli may be associated with ease of recognition.

A multiple correlation with asymmetry scores for faces as the dependent variable and asymmetry scores for cars, chairs, and houses as predictor variables revealed a significant positive correlation ($r = .74$, $p < .001$). Pairwise Pearson product-moment correlations between asymmetry scores for faces and each of the other stimulus types revealed significant and approximately equal correlations in each case ($r = .52$, .54, and .59, for faces and chairs, faces and houses, and faces and cars, respectively, $p < .01$ in all cases). The significant positive correlations between asymmetry scores for faces and the other three stimulus types support the existence of stable individual differences in hemispheric involvement in the recognition of visuo-spatial stimuli among right-handed individuals.

To further investigate the hypothesis that individual dextrals show stable patterns of hemispheric involvement across different perceptual tasks, subjects were divided into two groups according to whether they showed a LVF advantage for the recognition of chairs (Group LCHAIR, $N = 14$) or a RVF advantage for the recognition of chairs (Group RCHAIR, $N = 9$). One subject who showed no visual field asymmetry was omitted from this analysis. A repeated measures analysis of variance with Group (LCHAIR, RCHAIR) as a between-subjects factor and Stimulus Type (faces, houses, cars) as a within-subjects factor was performed on subjects' visual field difference scores. Subjects' data on chairs were omitted from this analysis since chair asymmetry scores constituted the classification criterion for grouping the subjects. The main effect of Group approached statistical significance ($F(1, 21) = 3.05$, $.05 < p < .10$) (see Fig. 2). A t test revealed that the LVF − RVF difference score, pooled across stimulus type, was significantly greater than zero for Group LCHAIR ($t(13) = 3.35$, $p < .01$), but not for Group RCHAIR ($t(8) = 1.71$, $p >$

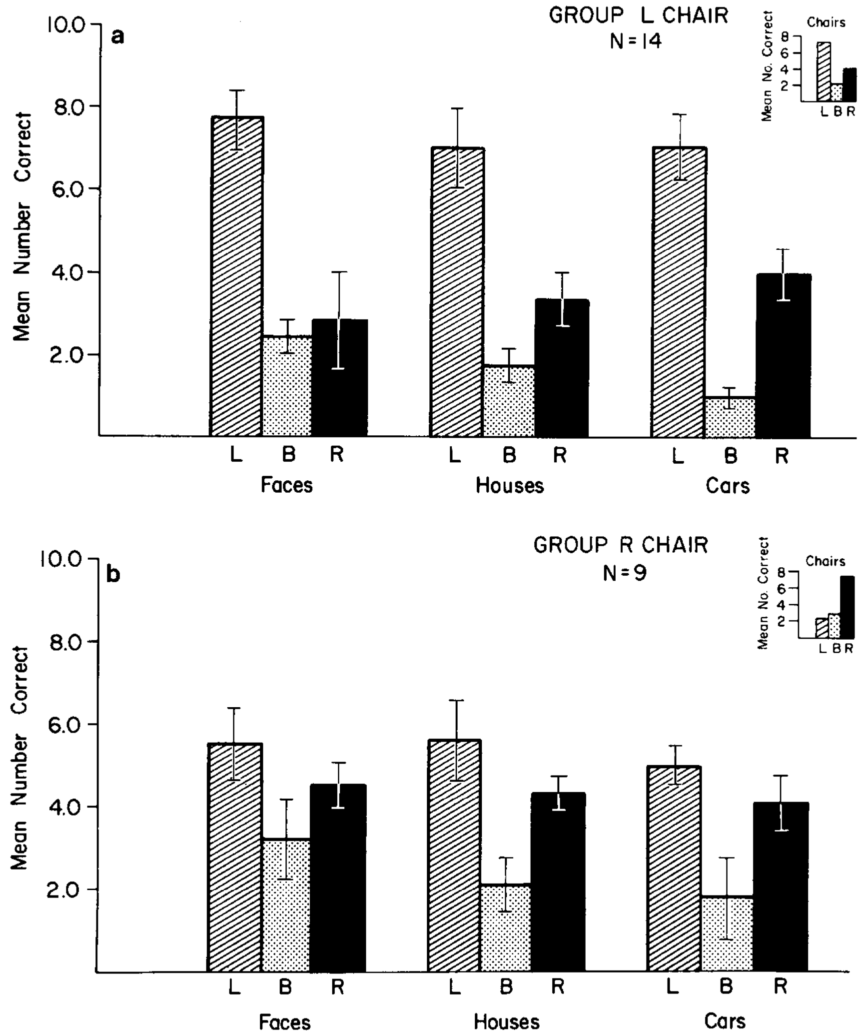

FIG. 2. (a) Mean number of L, B, and R trials for faces, houses, and cars for Group LCHAIR (subjects with better recognition of chairs in the LVF, $N = 14$). (b) Mean number of L, B, and R trials for faces, houses, and cars for Group RCHAIR (subjects with better recognition of chairs in the RVF, $N = 9$).

.10). It should be noted that for face recognition 8 of the 14 subjects in Group LCHAIR had visual field asymmetries in favor of the LVF that were larger than the asymmetry of any subject in Group RCHAIR. Although subjects in Group LCHAIR and RCHAIR differed more in asymmetry for the face task than for the house or car tasks, the Group × Stimulus Type interaction did not reach significance ($p > .10$).

A separate analysis of variance on order of report of double correct responses was performed in order to determine whether the significant LVF advantages shown by subjects in Group LCHAIR might be attributable to a left-to-right order of report bias. Results of this analysis revealed that the Group × Order of Report interaction was not significant (*F* less than unity). This suggests that the significant LVF advantages of subjects in Group LCHAIR were not based on an order of report bias.

Pearson product-moment correlations between asymmetry and performance level were nonsignificant and near zero for faces ($r = .07$), houses ($r = .08$), and cars ($r = .13$), all right-hemisphere-specialized tasks. As would be expected, a nonsignificant correlation was found between asymmetry and performance level for chair recognition, a nonlateralized task ($r = -.19$) (see Table 1). Recently, Levy et al. (1983) have suggested that for lateralized tasks both the finding of a significant correlation between asymmetry and performance level under unilateral presentation conditions and the finding of a nonsignificant correlation between asymmetry and performance level under bilateral presentation conditions are consistent with the hypothesis of individual differences in characteristic hemispheric arousal asymmetry. The present study, in which stimuli were presented bilaterally, provides a test of the Levy et al. (1983) predictions.

The Levy et al. arguments can best be understood by examining the covariance equations which they derived between asymmetry and performance level for unilateral and bilateral presentation conditions.

$$\mathrm{COV}_{A,S} = s_{\mathrm{L}}^2 - s_{\mathrm{R}}^2 \qquad \text{(unilateral condition)} \qquad (1)$$
$$\mathrm{COV}_{A',S'} = [1/2(s_L^2 - s_{\mathrm{R}}^2)] + [\mathrm{COV}_{\mathrm{B,L}} - \mathrm{COV}_{\mathrm{B,R}}] \qquad \text{(bilateral condition)} \qquad (2)$$

where both A and A' (asymmetry) $= p_{\mathrm{L}} - p_{\mathrm{R}}$; S (overall accuracy in

TABLE 1

Stimuli	$s_L{}^2$	$s_R{}^2$	$\mathrm{COV}_{B,L}$	$\mathrm{COV}_{B,R}$	$r_{A,S}$[a]	$r_{A'S'}$[b]
Faces	2.76^2	1.91^2	−1.61	−0.51	.07	.42*
Houses	3.12^2	1.92^2	−1.91	0.20	.08	.49*
Cars	2.39^2	1.98^2	0.15	−0.15	.13	.22
Chairs	2.61^2	2.68^2	−1.43	−0.17	−.19	−.03
Words	2.87^2	4.66^2	0.53	−1.27	.32	.54**
Line drawings	2.46^2	2.48^2	0.80	−1.49	−.18	.01

[a] $r_{A,S}$ is the correlation between asymmetry and performance level with bilateral responses included.

[b] $r_{A'S'}$ is the correlation between asymmetry and performance level with bilateral correct responses excluded.

*$p < .05$.

**$p < .01$.

the unilateral condition) = $p_L + p_R$; and S' (overall accuracy in the bilateral condition) = $p_B + 1/2(p_L + p_R)$, where p_L, p_R, and p_B are the proportions of correct unilateral left, unilateral right, and bilateral responses, respectively. (These equations are written for a right-hemisphere-specialized task such as face recognition. For a left-hemisphere-specialized task, L and R subscripts should be reversed.)

Levy predicts that $COV_{A,S}$ and the first bracketed term of $COV_{A'S'}$ will be positive for the following reason: Subjects are more variable in LVF than RVF performance on right-hemisphere-specialized tasks such as face recognition (i.e., $s_L^2 > s_R^2$), because of the arousal factor. Arousal in favor of the right hemisphere will tend to promote face processing and increase attention to the LVF, while arousal in favor of the left hemisphere will tend to interfere with face processing and will decrease attention to the LVF. Thus, subjects will tend to spread apart in LVF performance due to the arousal factor. For RVF performance, arousal in favor of the right hemisphere will tend to promote face processing but diminish attention to the RVF, while arousal in favor of the left hemisphere will tend to interfere with face processing but will increase attention to the RVF. Thus, relative to LVF variance, subjects will tend to be closer together in RVF performance, due to the arousal factor. In fact, our results bear out this prediction. On trials on which a unilateral correct response was made, $s_L^2 > s_R^2$ for faces, houses, and cars, all lateralized tasks, while $s_L^2 \approx s_R^2$ for chairs, a nonlateralized task (see Table 1). The positive value of the first bracketed term of $COV_{A'S'}$ is reflected by the positive correlations found between asymmetry and performance level for faces ($r = .42$, $p < .05$), houses ($r = .49$, $p < .02$), and cars ($r = .22$, $p > .10$) with bilateral correct trials excluded. For chairs, the correlation between asymmetry and performance level with bilateral responses excluded remains nonsignificant, but moves closer to zero ($r = -.03$, $p > .10$). This most likely reflects the fact that on the average, making bilateral correct responses leads to higher performance level but less asymmetry. Thus the correlation between asymmetry and performance level for chairs is negative (but nonsignificant) with bilateral correct responses excluded (see Table 1).

According to Levy et al. (1983), the arousal hypothesis further predicts that the second bracketed term of $COV_{A'S'}$ should be negative for the following reason. On right-hemisphere-specialized tasks, arousal asymmetry in favor of the right hemisphere should increase p_L and at the same time decrease p_B, leading to a negative covariance between p_L and p_B. To a limited degree, the covariance of asymmetry and performance level for these subjects may resemble the perceptual half-field erasure found in commissurotomy patients on bilateral tasks (e.g., Levy & Trevarthen, 1977; Milner, Taylor, & Sperry, 1968). While commissurotomy patients show extreme asymmetry on bilateral tasks, their maximal performance level is approximately 50%. Levy argues that $COV_{B,R}$ should be less negative than $COV_{B,L}$ for the following reason. On right-hemisphere-specialized tasks, arousal asymmetry in favor of the left hemisphere should lead to a relative increase in p_R as well as in p_B, because attention to the left and right visual fields should be more comparable.[3] In fact, we find that $COV_{B,L} < COV_{B,R}$ for faces and houses, the two most lateralized stimulus types, resulting in a negative value for the second bracketed term of $COV_{A'S'}$ (see Table 1). It should be noted that the frequency of bilateral correct responses was quite low for cars, making it difficult to meaningfully compare $COV_{B,L}$ and $COV_{B,R}$ for this stimulus type.

EXPERIMENT 2

Having demonstrated in Experiment 1 that individual subjects' asymmetry scores on a task that is nonlateralized for the group as a whole are highly related to their asymmetry scores on a right-hemisphere-specialized task (face recognition), Experiment 2 examines whether subjects' asymmetry scores on a nonlateralized task are also highly related to asymmetry scores on a left-hemisphere-specialized task (word recognition). The question of the relation between asymmetry scores on nonlateralized and left-hemisphere-specialized tasks was examined by reanalyzing some previously published data that were originally gathered to answer a different question (Levine & Banich, 1982). In particular, in Experiment 2 we investigate the relation of subjects' asymmetry scores on the naming of line drawings of common objects, a task that was previously shown to be nonlateralized for a group of dextrals, to their asymmetry scores on the recognition of corresponding words, which was previously shown to differentially involve the left hemisphere for these subjects.

The finding that subjects' laterality scores on tasks that are nonlateralized for the group as a whole are related to asymmetry scores on a left-hemisphere as well as a right-hemisphere specialized task would provide strong evidence that nonlateralized tasks are tapping individual differences in characteristic hemispheric reliance rather than error variance.

Method

Subjects

Sixteen male and sixteen female subjects consisting of University of Chicago students and staff were tested. All were right-handed with right-handed parents and had normal or

[3] One could also argue that arousal asymmetry in favor of the left hemisphere might lead to a relative increase in p_R but a decrease in p_B. Subjects with arousal asymmetry in favor of the left hemisphere would not be as proficient at face recognition as subjects with arousal asymmetry in favor of the right hemisphere, possibly resulting in less available processing capacity, and less frequent bilateral correct responses. This argument would predict that $COV_{B,L} > COV_{B,R}$, resulting in the second bracketed term of Eq. (2) being positive, rather than negative. This possibility is not supported by our data. It is, of course, possible that this factor operates, but is not as strong as the factor predicting $COV_{B,L} < COV_{B,R}$, suggested by Levy et al. (1983).

fully corrected vision according to self-report. None of these subjects had been tested in Experiment 1.

Stimuli and Procedure

As in Experiment 1, stimuli were bilaterally presented to binocular view in a Gerbrands two-channel tachistoscope (Model T-2B1). Stimuli consisted of 40 line drawings of common objects their 40 mirror images, and the 40 four- or five-letter words that name these objects. The pictures were black ink line drawings on white stimulus cards, and the words were typed in black capital letters (IBM Bookface) on white stimulus cards. The near point of each line drawing was located 2°3′ from central fixation. For both word and picture stimuli, a random digit ranging from 2 to 9 appeared at the center of each stimulus card. It should be noted that, similar to Experiment 1, the digit was reported incorrectly on only 2.5% of the total number of trials administered.

Trials were blocked by stimulus type and the subject's task was first to report the center digit and then to name the two stimuli with no constraint on reporting order. Each subject was presented with 20 bilateral picture trials and 20 bilateral word trials. In an attempt to equate overall performance level for pictures and words, subjects were assigned different exposure durations for the two stimulus types on the basis of their performance on practice trials. Average exposure duration for pictures was 23 msec and that for words was 79 msec. A more detailed description of the procedure and stimuli is presented in Levine and Banich (1982).

Results

As reported previously (Levine & Banich, 1982), a t test on difference scores for words and line drawings revealed a significant advantage in favor of the right visual field for words ($t(31) = 3.33, p < .005$), and no visual field asymmetry for line drawings ($t(31) = 1.06, p > .10$). Moreover, the asymmetry score for words significantly differs from that for line drawings ($t(31) = 4.33, p < .001$). Thus, while word recognition differentially involves the left hemisphere, the recognition of corresponding line drawings shows no hemispheric asymmetry (see Fig. 3). It should be noted that 69% of our subjects showed a RVF advantage for the recognition of words, whereas only 37% showed a RVF advantage for the recognition of line drawings.

The additional analyses of the data performed for the purpose of the present study revealed a significant Pearson product-moment correlation between subjects' laterality scores for line drawings and words ($r = .45$, $p < .01$). As in Experiment 1, subjects were divided into two groups on the basis of whether they showed a LVF advantage on the nonlateralized picture recognition task (Group LPIC, $N = 18$) or a RVF advantage on the nonlateralized picture recognition task (Group RPIC, $N = 12$). Two subjects who did not show any asymmetry on the picture recognition task were excluded from this analysis.

Paralleling the results of Experiment 1, t tests revealed that the mean asymmetry score for words was significantly different for Groups RPIC and LPIC ($t(28) = 2.56, p < .02$) and that Group RPIC showed a significant RVF advantage for word recognition ($t(11) = 6.70, p < .0001$), while Group LPIC did not ($t(17) = 1.13, p > .10$) (see Fig. 4).

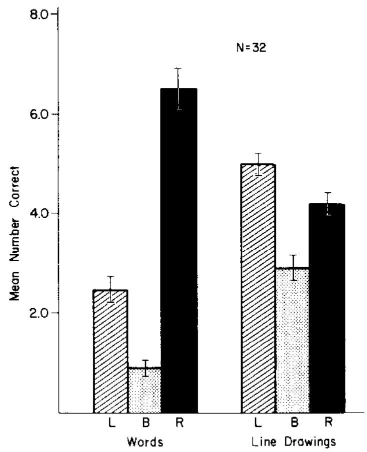

FIG. 3. Mean number of trials on which unilateral correct responses were made in the LVF (L), unilateral correct responses were made in the RVF (R), and bilateral correct responses (B) were made for words and line drawings, across all subjects.

An analysis of variance on the order of report of double correct responses, pooled across pictures and words, was performed in order to determine whether the LVF bias of subjects in Group LPIC might be related to a left-to-right order-of-report bias. In fact, this analysis revealed that Group LPIC reported in a left to right order significantly more often than in a

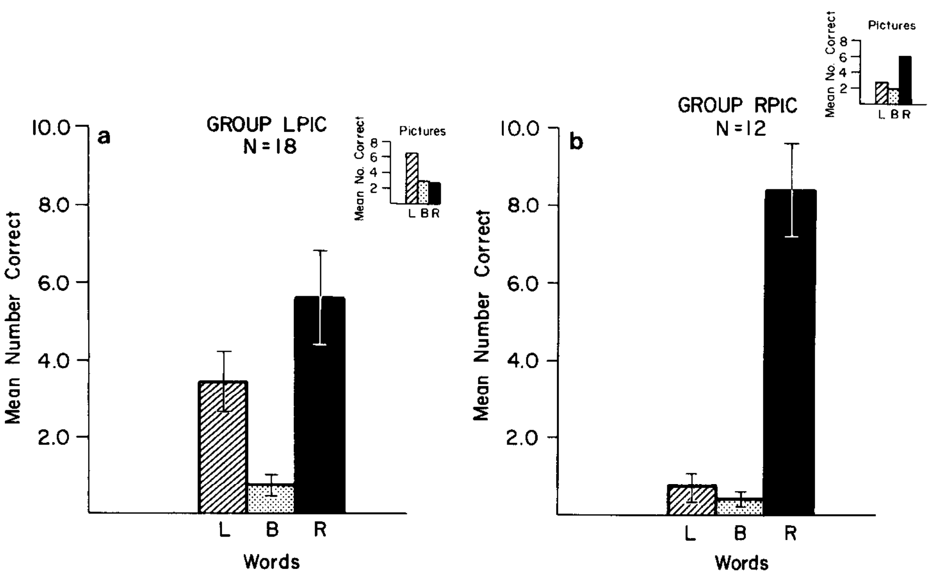

FIG. 4. (a) Mean number of L, B, and R trials for words in Group LPIC (subjects with better recognition of line drawings in the LVF). (b) Mean number of L, B, and R trials for words for Group RPIC (subjects with better recognition of line drawings in the RVF).

right-to-left order ($p < .05$), while Group RPIC showed no order-of-report asymmetry. The finding of a report order bias in Experiment 2 but not in Experiment 1 may be related to the different response modes used, i.e., verbal report vs. recognition from arrays, respectively. The report order bias for subjects in Group LPIC but not Group RPIC might account for the group differences in asymmetry on the word and picture tasks. Arguing against this possibility, however, is the absence of a significant report order bias in Experiment 1, yet a very similar pattern of results in Experiments 1 and 2. A possible explanation for such report order biases is that they are induced by asymmetric hemispheric reliance. This possibility is supported by numerous studies reporting that hemispheric arousal asymmetries result in contralateral motoric and attentional biases (e.g., Gur & Reivich, 1980; Gur, Gur, & Harris, 1975; Trevarthen, 1974).

Paralleling the results for the lateralized tasks in Experiment 1 (face, house, and car recognition), the Pearson product-moment correlation between asymmetry and performance level for words was not significant with bilateral correct responses included ($r = .32$, $p > .05$), but was significant when bilateral correct responses were excluded ($r = .54$, $p < .001$). Paralleling the results for the nonlateralized chair recognition task in Experiment 1, the correlation between asymmetry and performance level for the nonlateralized line drawing task is nonsignificant with bilateral responses included ($r = -.18$) and moves closer to zero with bilateral responses excluded ($r = .01$) (see Table 1). These correlations are consistent with the Levy et al. (1983) arousal hypothesis and can best be understood by examining the covariance equations given under Results for Experiment 1 and the values found for the two terms of this equation, which are reported in Table 1. Analogous to the results of Experiment 1, for word recognition, $s_R^2 > s_L^2$ and $COV_{B,R} < COV_{B,L}$, consistent with Levy's hypothesis.

GENERAL DISCUSSION

Results of Experiments 1 and 2, considered together, support the hypothesis of characteristic individual differences among dextrals in patterns of hemispheric involvement across right-hemisphere-specialized, left-hemisphere-specialized, and nonlateralized tasks. These differences may be accounted for by individual variations in underlying hemispheric specialization. However, the evidence provided by Wada test results (Wada & Rasmussen, 1960; Rasmussen & Milner, 1977), deficits in unilaterally brain-damaged patients (Milner, 1974; Warrington & Taylor, 1973), and the capacities of the left and right hemispheres of split brain patients (e.g., Levy et al., 1972; Sperry, 1974) do not support such variations among dextrals in the direction of hemispheric specialization. An alternative hypothesis is that while dextrals are invariant in the direction of hemispheric specialization, they vary in patterns of hemispheric involvement in cognitive tasks. These differences in hemispheric involvement in cognitive tasks may be attributable to stable individual differences in hemispheric arousal asymmetry, as has been suggested by Levy et al. (1983).

Although it is not possible to definitively support either of these hypotheses on the basis of the present results, several findings in the present study seem more consistent with the hypothesis that dextrals differ in characteristic hemispheric arousal asymmetry rather than in hemispheric specialization. First, the finding of a significant correlation between asymmetry scores for faces, a right-hemisphere-specialized task, and chairs, a nonlateralized task, comparable in magnitude to the correlations between asymmetry scores for faces and houses, and faces and cars, all right-hemisphere-specialized tasks, would be predicted by the arousal hypothesis. In contrast, the specialization hypothesis might predict a smaller correlation between asymmetry scores for faces and chairs than between asymmetry scores for two right-hemisphere-specialized tasks. Second, the arousal hypothesis leads to the prediction that subjects dichotomized on the basis of their asymmetry scores on a nonlateralized task (chairs or line drawings) would differ in asymmetry scores on lateralized tasks (e.g., face recognition and word recognition, in particular). This would not necessarily be predicted on the basis of the specialization hypothesis. Finally, the nonsignificant correlations obtained between asymmetry and performance level on the right-hemisphere-specialized tasks (Experiment 1) and the left-hemisphere-specialized task (Experiment 2) are consistent with the arousal hypothesis. Further, the values obtained for the two terms of $COV_{A'S'}$ for faces and houses, the two most right-hemisphere-lateralized stimulus types, and words, a left-hemisphere-lateralized task, are also consistent with the arousal hypothesis. In fact, the specialization hypothesis could not account for the values obtained for the two terms of the covariance equations without positing an arousal factor, or some other factor(s) that is similar to the arousal factor in its effects.

In summary, the present results support the existence of individual variations in hemispheric involvement in perceptual tasks among dextrals. Some dextrals show evidence of relatively greater right-hemisphere involvement on a nonlateralized task and on lateralized spatial tasks (Experiment 1) as well as on a nonlateralized task and a lateralized verbal task (Experiment 2). In contrast, other dextrals show evidence of relatively greater left-hemisphere involvement on these tasks. These findings are consistent with the Levy et al. (1983) hypothesis that individual differences in hemispheric reliance among dextrals are attributable to characteristic differences in arousal asymmetry between the hemispheres. Currently we are further investigating the existence of individual variations in hemispheric reliance by testing individual dextrals and sinistrals on nonlateralized, left-hemisphere-specialized, and right-hemisphere-specialized tasks. The finding of a relation among individuals' scores on all three tasks would strengthen the argument for characteristic patterns of asymmetric hemispheric reliance.

The results of the present study suggest that standard laterality tasks can potentially provide two types of information. First, as is widely recognized, the average asymmetry score for the group of subjects tested may reveal underlying patterns of hemispheric specialization for the task performed. Second, examination of individual subjects' asymmetry scores across different laterality tasks may reveal consistent individual differences in relative hemispheric reliance that are superimposed on underlying hemispheric specialization for specific cognitive tasks.

REFERENCES

Bakan, P. (1969). Hyponotizability, laterality of eye movements, and functional brain asymmetry. *Perceptual and Motor Skills*, **28**, 927–932.

Benton, A. L., & Van Allen, M. W. (1968). Impairment in facial recognition in patients with cerebral diseases. *Cortex*, **4**, 344–358.

Burton, L., & Levy, J. (1984). Lateral differences among right-handers for face recognition and judgment of facial emotion as a function of processing speed. In preparation.

Carter, G. L., & Kinsbourne, M. (1979). The ontogeny of right cerebral lateralization of spatial mental set. *Developmental Psychology*, **15**, 241–245.

Dabbs, J. M., Jr. (1980). Left–right differences in cerebral blood flow and cognition. *Psychophysiology*, **17**, 548–551.

Dabbs, L., & Choo, R. (1980). Carotid blood flow predicts specialized mental ability. *Neuropsychology*, **18**, 711–713.

DeRenzi, E., & Spinnler, H. (1966). Facial recognition in brain-damaged patients. *Neurology*, **16**, 145–152.

Duda, P. D., & Kirby, H. W. (1980). Effects of eye-movement controls and frequency levels on accuracy of word recognition. *Perceptual and Motor Skills*, **50**, 979–985.

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for kit of factor referenced cognitive tests*. Princeton, NJ: Educational Testing Service.

Furst, C. J. (1976). EEG asymmetry and visuospatial performance. *Nature, (London)*, **260**, 254–255.

Gur, R. E., & Gur, R. C. (1975). Defense mechanisms, psychosomatic symptomatology, and conjugate lateral eye movements. *Journal of Consulting and Clinical Psychology*, **43**, 416–420.

Gur, R. E., Gur, R. C., & Harris, L. J. (1975). Cerebral activation, as measured by subjects' lateral eye movements, is influenced by experimenter location. *Neuropsychologia*, **13**, 35–44.

Gur, R. E. & Reivich, M. (1980). Cognitive task effects on hemispheric blood flow in humans: Evidence for individual differences in hemispheric activation. *Brain and Language*, **9**, 78–92.

Hines, D. (1978). Visual information processing in the left and right hemispheres. *Neuropsychologia*, **16**, 593–600.

Ladavas, E., Umiltà, C., and Ricci-Bitti, P. E. (1980). Evidence for sex differences in right hemisphere dominance for emotions. *Neuropsychologia*, **18**, 361–367.

Leehey, S. C., Carey, S., Diamond, R. C., & Cahn, A. (1978). Upright and inverted faces: The right hemisphere knows the difference. *Cortex*, **14**, 411–419.

Levine, S. C., & Banich, M. T. (1982). Lateral asymmetries in the naming of words and corresponding line drawings. *Brain and Language*, **17**, 34–45.

Levine, S. C., & Koch-Weser, M. (1982). Right hemisphere superiority in the recognition of famous faces. *Brain and Cognition,* **1,** 10–22.

Levy, J. (1969). Possible basis for the evolution of lateral specialization of the human brain. *Nature, (London),* **224,** 614–615.

Levy, J., Heller, W., Banich, M. T., & Burton, L. (1983). Are variations among right-handers in perceptual asymmetries caused by characteristic arousal differences between hemispheres? *Journal of Experimental Psychology: Human Perception and Performance,* **9,** 329–359.

Levy, J., & Trevarthen, C. (1977). Perceptual, semantic, and phonetic aspects of elementary language processes in split-brain patients. *Brain,* **100,** 105–118.

Levy, J., Trevarthen, C., & Sperry, R. (1972). Perception of bilateral chimeric figures following hemispheric deconnexion. *Brain,* **95,** 61–68.

MacKavey, W., Curcio, F., & Rosen, J. (1975). Tachistoscopic word recognition performance under conditions of simultaneous bilateral presentation. *Neuropsychologia,* **13** 27–33.

Mancuso, R. P., Lawrence, A. F., Hintze, R. W., & White, C. T. (1979). Effect of altered central and peripheral visual field stimulation on correct recognition and visual evoked response. *International Journal of Neuroscience,* **9,** 113–122.

McKeever, W. F., Suberi, M., & Van Deventer, A. D. (1972). Fixation control in tachistoscopic studies of laterality effects: Comments and data relevant to Hines' experiment. *Cortex,* **8,** 473–479.

Milner, B. (1960). *Impairment of visual recognition and recall after right temporal lobectomy in man.* Paper presented at Psychonomic Society Meeting, Chicago.

Milner, B. (1968). Visual recognition and recall after the right temporal lobe excision in man. *Neuropsychologia,* **6,** 191–209.

Milner, B. (1974). Hemispheric specialization: Scope and limits. In F. O. Schmitt & F. G. Worden (Eds.), *The neurosciences: third study program.* Cambridge, MA: MIT Press.

Milner, B., Taylor, L., & Sperry, R. W. (1968). Lateralized suppression of dichotically presented digits after commissural section in man. *Science,* **161,** 184–186.

Rasmussen, T., & Milner, B. (1977). The role of early left-brain injury in determining lateralization of cerebral speech functions. In S. J. Diamond & D. A. Blizard (Eds.), *Evolution and Lateralization of the Brain.* New York: N.Y. Acad. Sci.

Ray, W. J., Newcombe, N., Semon, J., & Cole, P. M. (1981). Spatial abilities, sex differences, and EEG functioning. *Neuropsychologia,* **19,** 719–722.

Rizzolatti, G., Umiltà, C., & Berlucchi, G. (1971). Opposite superiorities of right and left cerebral hemispheres in discriminative reaction time to physiognomic and alphabetical material. *Brain,* **94,** 246–258.

Sackheim, H. A., Packer, I. K., & Gur, R. C. (1977). Hemisphericity, cognitive set, and susceptibility to subliminal perception. *Journal of Abnormal Psychology,* **86,** 624–630.

Sperry, R. W. (1974). Lateral specialization in the surgically separated hemispheres. In F. O. Schmitt & F. G. Worden (Eds.), *The neurosciences: third study program.* Cambridge, MA: MIT Press.

St. John, R. C. (1981). Lateral asymmetry in face perception. *Canadian Journal of Psychology,* **35,** 213–223.

Teng, E. L. (1981). Dichotic ear difference is a poor indicator for the functional asymmetry between the cerebral hemispheres. *Neuropsychologia,* **19,** 235–240.

Teuber, H.-L. (1974). Why two brains? In F. O. Schmitt & F. G. Worden (Eds.), *The neurosciences: third study program.* Cambridge, MA: MIT Press.

Trevarthen, C. (1974). Functional relations of disconnected hemispheres with brain stem and with each other: Monkey and man. In M. Kinsbourne & W. L. Smith (Eds.), *Hemispheric deconnexion and cerebral functions.* Springfield, IL: Charles C. Thomas.

Wada, J., & Rasmussen, T. (1960). Intracarotid injection of sodium amytal and the lateralization of cerebral speech dominance. Experimental and clinical observations. *Journal of Neurosurgery,* **17,** 266–282.

Warrington, E. K., & James, M. (1967). An experimental investigation of facial recognition in patients with unilateral cerebral disease. *Cortex,* **3,** 317–326.

Warrington, E. K., & Taylor, A. M. (1973). The contribution of the right parietal lobe to object recognition. *Cortex,* **9,** 152–164.

White, M. (1969). Laterality differences in perception: A review. *Psychological Bulletin,* **72,** 387–405.

Yin, R. (1969). Looking at upside-down faces *Journal of Experimental Psychology,* **81,** 141–147.