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Individual Differences in Lateralization: Effects of Gender and Handedness

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Male and female left- and right-handers participated in 3 experiments designed to investigate 3 components of performance asymmetry in lateralized tasks. Experiment 1 used a consonant-vowel-consonant (CVC) identification task measuring quantitative differences in hemispheric abilities and hemispheric control and qualitative differences in hemispheric strategies. The quantitative data revealed that left-handers have a smaller performance asymmetry than do right-handers and that both groups have the same degree of increased accuracy when stimuli are presented bilaterally. Handedness affected the qualitative measures of men, not of women. Experiment 2 used nominal and physical letter-matching tasks with bilateral presentations and measured the flexibility of callosal function. The results suggest that left-handers have less flexible interhemispheric communication than do right-handers and show no effect of gender. Experiment 3 used a chair identification task indexing hemispheric arousal bias. Left-handers tended to have more aroused right than left hemispheres, whereas the distribution of right-handers was centered around 0 arousal bias. Intertask analyses revealed a relationship between arousal bias and metacontrol, where individuals with more aroused right hemispheres tended to use a right-hemisphere strategy in the bilateral condition of the CVC experiment. Intercorrelations between measures from the experiments revealed only a limited relationship between metacontrol patterns in the CVC task and a measure of callosal flexibility in the physical letter-matching task. The results are discussed in the context of the relationships between dimensions of hemispheric asymmetry.

Functional hemispheric asymmetry in healthy individuals is often inferred from performance asymmetries on lateralized experimental tasks. Many tasks requiring linguistic abilities result in better performance in the right visual field (RVF), that is, in a right visual field advantage (RVFA), while many tasks requiring visuospatial abilities result in better performance in the left visual field (LVF), resulting in an LVF advantage (LVFA). These results are interpreted as reflecting the relative abilities of the two hemispheres in these types of cognitive tasks. A large body of research has focused on the relationship between participant attributes, such as gender and handedness, and these performance asymmetries. Behavioral studies have suggested that left-handers are less asymmetrical than are right-handers, and conclusions about the effects of gender have been contradictory (Hellige, 1993; Zaidel, Aboitiz, Clarke, Kaiser, & Matteson, 1995). In addition, anatomical (Aboitiz, Scheibel, Fisher, & Zaidel, 1992; Clarke, Lufkin, & Zaidel, 1993; Clarke & Zaidel, 1994; Habib et al., 1991; Witelson & Nowakowski, 1991) and physiological (Galaburda, Rosen, & Sherman, 1990) studies have suggested that there are complex interactions among gender, handedness, and brain organization.

Recent studies of individual differences in hemispheric specialization (e.g., Boles, 1991, 1992, 1996; Hellige et al., 1994) have looked at laterality as a multidimensional construct and have focused on the lateralization patterns of components of cognitive processes (e.g., visual lexical, auditory lexical, visual spatial). The general conclusion has been that individual differences for one component or one dimension may be independent of individual variations on other dimensions. This view contrasts with the predictions of the neurodevelopmental model proposed by Geschwind and Galaburda (1987) that proposes that levels of prenatal testosterone affect hemispheric development in systematic ways that predict specific and diverse relationships between performance asymmetries on tasks that tap different mental

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abilities (but see Bryden, McManus, & Bulman-Fleming, 1994, [and ensuing commentaries] for a critique of this model).

Our experiments tackle the question of individual differences from a slightly different direction. We attempted to explore these differences on different components of the measure of hemispheric specialization, the performance asymmetry, defined a priori. We reasoned that the magnitude of performance asymmetries can be a result of some combination of three possibly independent factors: asymmetry in hemispheric abilities for the task, flexibility of callosal connectivity, and asymmetry of hemispheric baseline arousal levels. For example, left-handers as a group generally yield smaller RVFAs for linguistic materials than do right-handers. This result could be due to greater right hemisphere (RH) involvement in language in this group, greater callosal interaction in left-handers, or that left-handers as a group may tend to have a more aroused RH than left hemisphere (LH; but see Levy, Heller, Banich, & Burton, 1983), which biases their responses toward stimuli in the left side of space and results in more accurate or faster responses on LVF trials, hence a smaller RVFA. In each of the experiments reported below, we used tasks that previous research has suggested reflect one of these factors more than the others. We tested right- and left-handed men and women, using all of the tasks, in an attempt to investigate the effects of gender and handedness on these different aspects of hemispheric functioning. We also computed intercorrelations between the tasks, so we could examine possible relationships between the factors.

The experiments we present constitute a replication (Experiment 1) and extensions (Experiments 2 and 3) of the results reported by Hellige et al. (1994). Similar questions concerning sex differences in dimensions of hemispheric specialization and interhemispheric interaction were addressed by Zaidel et al. (1995). In Experiment 1, we used a syllable identification paradigm, which is believed to reflect hemispheric differences in ability and in processing strategy as well as certain characteristics of interhemispheric integration and control. In Experiment 2, we used a letter-matching task that allows for an estimation of individual differences in flexibility of callosal transfer. In Experiment 3, we used a chair identification task, which can be thought of as a visual analogue of the dichotic listening task with stimuli for which there is bilateral ability. This task is believed to measure hemispheric arousal bias. The method, results, and discussion are first presented separately for each experiment. We then present the results and discussion of the intertask analyses. Some individuals were excluded for various reasons from each experiment; so for each task, we analyzed the data from all of the participants who completed that experiment. The intercorrelations of the tasks were computed on the maximum number of individuals who completed both relevant tasks.

Experiment 1: Hemispheric Abilities and Integration for CVC Syllable Identification

To tap hemispheric abilities, we used the lateralized consonant–vowel–consonant (CVC) identification task developed by Levy et al. (1983) and used extensively by Hellige and his colleagues (Eng & Hellige, 1994; Hellige et al., 1994; Hellige, Cowin, & Eng, 1995; Hellige, Cowin, Eng, & Sergent, 1991; Hellige, Taylor, & Eng, 1989). Participants were presented with CVC syllables in each unilateral visual field and in a bilateral condition where the same CVC is presented in both visual fields. The task is to identify (i.e., name) the letters making up the stimulus.

It has proven particularly useful to compare the number of times participants make an error on the first letter while reporting the last letter correctly with the number of times they make an error on the last letter while reporting the first letter correctly. This manner of scoring the responses allowed us to define hemispheric asymmetry in both quantitative and qualitative terms. Quantitative differences were reflected in an RVFA in overall accuracy reflecting the greater capability of the LH to process strings of letters. Qualitative differences in error patterns are also found between the hemispheres. The general finding is that, for LVF stimuli, more errors are made on the last letter than on the first letter, while, for RVF stimuli, there is a smaller difference between first and last letter errors (e.g., Cherry, Hellige & McDowd, 1995; Eng & Hellige, 1994; Hellige et al., 1989, 1994, 1995; Hellige & Cowin, 1996; Levy et al., 1983; Luh & Levy, 1995). This has been interpreted as reflecting sequential, letter-by-letter processing by the RH because it lacks phonetic processing ability and, as a consequence, treats the CVC stimulus as three individual letters. By way of contrast, the more equal number of first letter and last letter errors on RVF–LH trials suggests that the LH distributes attention more quickly or more evenly across the three letters than does the RH, perhaps because of its superior phonetic processing ability. Patterns of errors in the two visual fields may thus be indicative of the processing strategies of the cerebral hemispheres that are related to hemispheric differences in both phonological abilities and deployment of attentional resources.

Overall error rates on bilateral trials are typically lower than those on both types of unilateral trials, reflecting that the amount of information about each letter is doubled in the bilateral condition. This measure of bilateral gain may be taken as an index of the efficiency with which the two hemispheres coordinate processing. However, despite the finding that there is an RVF–LH advantage for CVC identification on unilateral trials, the qualitative error (QE) pattern obtained on bilateral visual field (BVF) trials has not been identical to the error pattern obtained on RVF–LH trials. Instead, on BVF trials, there are fewer normalized first letter errors and more normalized last letter errors than on RVF–LH trials, with this shift away from the RVF–LH pattern often being so dramatic that the normalized BVF error pattern does not differ from the normalized LVF–RH error pattern (e.g., Cherry et al., 1995; Eng & Hellige, 1994; Hellige, 1993, 1995; Hellige et al., 1989, 1994, 1995). However, Luh and Levy (1995) reported that overall the BVF QE pattern was in between the unilateral patterns, with an interesting relationship between the BVF pattern and quantitative asymmetry: The BVF pattern was shifted toward the RVF pattern for participants with a large RVFA and toward the LVF pattern for participants with small asymmetries. This shift of the BVF error patterns is interpreted as an *index of metacontrol,* that is, the hemisphere whose processing strategy has the most effect on error patterns when both hemispheres can contribute to the response.

Hellige et al. (1994) administered the CVC identification task to groups of left- and right-handed men and women. In general, they found the same types of quantitative and qualitative hemispheric differences among the groups. The left-handers revealed a smaller RVFA, consistent with other reports of reduced LH superiority for phonetic processing in left-handers as compared with right-handers (e.g., Hellige, 1993). Both handedness groups showed the same amount of bilateral gain and the same pattern of qualitative difference in error pattern between the hemispheres. The qualitative scores revealed a main effect of gender in both handedness groups, with women showing larger differences between first letter and last letter errors than do men. In terms of metacontrol, the qualitative pattern in the bilateral trials was more similar to the pattern in the LVF–RH for 64.8% of the right-handers and for 47.5% of the left-handers.

One purpose of our experiment was to examine the consistency of the handedness and gender differences reported by Hellige et al. (1994). The second purpose was to explore relations between quantitative and qualitative measures, and the third purpose was to determine whether individual differences in this task were related to the measure of interhemispheric gating that was estimated in Experiment 2 or to the type of characteristic arousal bias that was measured in Experiment 3.

Method

Participants. The participants were 74 right-handed (39 women and 35 men) and 32 left-handed (15 women and 17 men) undergraduates from the University of California, Los Angeles, and the University of Southern California. All received course credit for their participation. Handedness was assessed using a 10-item variant of the Edinburgh Handedness Inventory (Oldfield, 1971). The right-handers were strongly right-handed and reported no familial sinistrality. The left-handers indicated that they used their left hand exclusively for writing and for at least two other categories on the questionnaire (e.g., throwing a ball, brushing one's teeth). Familial sinistrality was not a criterion for inclusion of left-handers. All of the participants reported that they had normal or corrected-to-normal visual acuity. None of the participants had been exposed to any other language except English before the age of 6. The participants completed the three experiments in two sessions, approximately 1 week apart. In the first session, they performed the two letter-matching tasks assessing callosal connectivity (Experiment 2). In the second session, they always performed the chair identification task (Experiment 3) first and then the CVC identification task (Experiment 1). Each session lasted approximately 30–45 min.

Design. The CVC identification task used by Levy et al. (1983) and Hellige et al. (1989) was used. Participants were presented with CVC trigrams and reported the letters making up the stimuli. The stimuli were presented unilaterally to the left or right visual field, or bilaterally, where the identical stimulus was presented in both visual fields. The errors that participants made in reporting the letters were categorized into three types: first errors (FE), the first letter was incorrect and the last letter was correct; last errors (LE), the last letter was incorrect and the first letter was correct; and other errors (OE), all other types of errors.

Stimuli and procedure. The stimuli were 111 CVC trigrams created from the set of consonants, *D, F, G, K, S, T, P,* and three vowels, *O, A,* and *E.* All were presented vertically with their inner edge 1.5° of visual angle from fixation. The trigrams subtended 0.5° horizontally and 2.0° vertically. The stimuli were presented as white on a gray background using a 10-point Monaco font. The experimental trials were presented in three blocks of 37 trials, where the first trial was not scored. Order of the trials was pseudorandom, with the constraint that each presentation condition preceded the others an equal number of times. To achieve a 50% error rate, we titrated exposure duration of the stimuli in 15 ms intervals after each trial. If participants made an error, the next stimulus was shown for 15 ms longer. If they reported all three letters correctly, exposure duration was titrated down by 15 ms. The maximum exposure duration was 210 ms. Participants completed 37 trials as practice before beginning the experimental trials. The order of events on each trial was the following. A 1,000-Hz tone sounded to alert the individual that the trial was beginning, a fixation cross appeared for 2 s, then the stimuli were shown for the appropriate duration. A bilateral pattern mask consisting of horizontal lines appeared for 200 ms immediately after the stimulus. The participant pronounced the syllable and then spelled it. The experimenter typed the response into the computer; after 2 s, the next trial began. The experiment was run on a MAC IISI computer, which presented the stimuli, computed exposure durations, and collected the responses.

Results

Exposure duration of the stimuli in this experiment was titrated across the three visual presentation conditions to achieve an overall error rate of approximately 50%. In fact, our overall error rate was 47%, and the mean exposure durations were approximately equal for the three visual presentation conditions (LVF = 87 ms, RVF = 91 ms, BVF = 89 ms). We analyzed the data of 30 left-handers (13 women and 17 men) and 64 right-handers (37 women and 27 men).

Quantitative asymmetries. We performed a three-way analysis of variance (ANOVA) with handedness and gender as the between-group variables and visual field (LVF, RVF, BVF) as the within-subject variable. The percentage of errors in each visual field was the dependent variable. The three-way interaction between these factors was not significant ($p > .5$). Gender did not interact with handedness or visual field and did not result in a main effect ($p > .5$). The two-way interaction between handedness and visual field approached significance, $F(2, 180) = 2.85, p = .06$. A test of the simple interaction between handedness and the unilateral visual fields (excluding the BVF condition) was significant, $F(1, 90) = 4.53, p < .05$. The RVFA for right-handers was significant, $F(1, 62) = 43.97, p < .0001$; while for left-handers, it was not, $p > .1$. These patterns are illustrated in Figure 1. The main effect of handedness was not significant ($p > .7$) and of visual field was highly significant, $F(2, 180) = 58.81, p < .0001$. Participants made the most errors in the LVF ($M = 55.41\%$), less in the RVF ($M = 48.05\%$), and least in the BVF ($M = 39.98\%$). The RVFA overall was significant, $F(1, 90) = 37.82, p < .0001$,

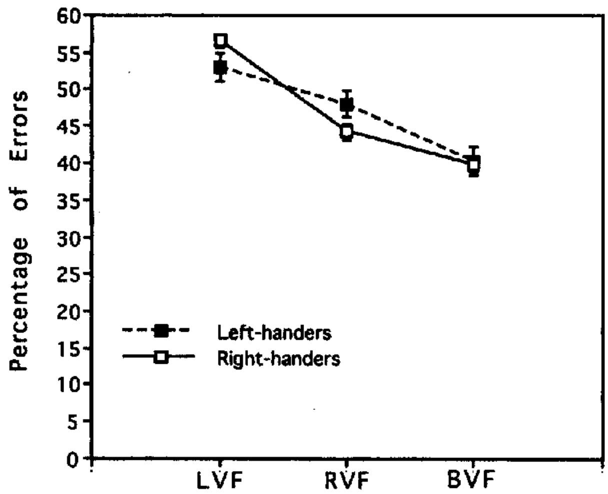

Figure 1. Percentage of consonant–vowel–consonant identification errors for left- and right-handers in each of the three conditions: left visual field (LVF), right visual field (RVF), and bilateral visual field (BVF).

as was bilateral gain (RVF vs. BVF), $F(1, 90) = 17.08$, $p < .0001$.

The percentage of error scores suggest that this is an LH task (there is an overall RVFA) and that left-handers evince a smaller performance asymmetry than do right-handers because they make less errors than right-handers do in the LVF and more errors than right-handers do in the RVF. These differences between the handedness groups approach significance, in the LVF, $F(1, 90) = 3.13$, $p = .08$, in the RVF, $F(1, 90) = 3.83$, $p = .054$. Left- and right-handers revealed the same degree of bilateral gain.

Qualitative asymmetries. To investigate closely the effects of handedness and gender on the patterns of errors in the visual fields, we computed a QE index from Levy et al. (1983). This index is computed as the normalized difference between FEs and LEs in each visual field (QE = [LE − FE]/total errors). Recall that an LE occurs if the last letter is missed but the first is reported correctly and that an FE occurs if the first letter is missed but the last letter is correct (correctness of the vowel is irrelevant).

The QE scores were analyzed with a three-way ANOVA, with gender and handedness as the between-groups variables and visual field as the within-subject variable. The QE index in each visual field was the dependent variable. The three-way interaction approached significance, $F(2, 180) = 3.04$, $p = .0503$. This pattern is illustrated in Figure 2. Planned comparisons revealed that female left- and right-handers do not differ from each other ($p > .5$), while male left- and right-handers do, $F(1, 42) = 5.92$, $p < .05$. For men, there is a simple interaction of handedness and visual field, $F(2, 84) = 3.65$, $p < .05$. As can be seen in the figure, left- and right-handed men differ in the LVF, $F(1, 42) = 15.77$, $p < .0005$, but not in the other visual fields ($p > .5$). The two-way interaction between gender and visual field approached significance, $F(2, 180) = 2.67$, $p = .07$, again with male left-handers having higher QE scores than do the other groups (34.09 vs. 21.20 for female left-handers, 21.34 for male right-handers, and 24.53 for female right-handers). However, both right-handers and left-handers showed the expected qualitative difference between the hemispheres: QE scores were significantly higher in the LVF than in the RVF, for right-handers, $F(1, 62) = 32.68$, $p < .0001$, for left-handers, $F(1, 28) = 43.28$, $p < .0001$. The main effects of gender and handedness were not significant ($p > .1$), while the main effect of visual field was significant, $F(2, 180) = 33.39$, $p < .0001$. Analyses of the handedness groups separately revealed that, for right-handers, there is a Gender × Visual Field interaction, $F(1, 62) = 10.80$, $p < .005$, such that women have larger QE differences between the LVF and RVF than do men. This interaction did not appear in the left-handed sample.

Following Hellige et al. (1994), we computed a CVC bias score for each participant, as an indication of the extent to which the pattern of errors obtained on the bilateral trials was more similar to the qualitative pattern obtained on the LVF–RH versus RVF–LH trials. Specifically,

$$\text{CVC bias} = |\text{LVFqe} - \text{BVFqe}| - |\text{RVFqe} - \text{BVFqe}|,$$

where LVFqe is the QE score obtained on LVF–RH trials, RVFqe is the score obtained on RVF–LH trials, and BVFqe is the QE score obtained on bilateral trials. By taking the absolute value of the (LVFqe − BVFqe) difference score, the first part of this equation provides a measure of the difference between qualitative error patterns on LVF–RH trials and bilateral trials, regardless of the direction of any difference between the two scores. Likewise, the second part

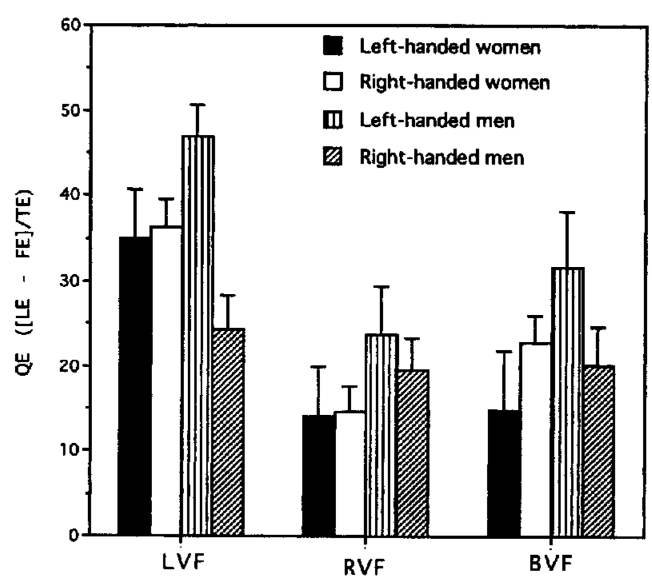

Figure 2. Qualitative error (QE) scores obtained during the consonant–vowel–consonant identification task for each condition: left visual field (LVF), right visual field (RVF), and bilateral visual field (BVF). Higher values of QE reflect a bigger difference between the relative frequency of errors on the last letter and the relative frequency of errors on the first letter. FE = first errors; LE = last errors; TE = total errors.

of the equation provides a measure of the difference between quantitative error patterns on RVF/LH and bilateral trials, again regardless of the direction of any difference between the two scores. As a result, the CVC bias index takes on positive values when the bilateral error pattern is more similar to the RVF/LH pattern than to the LVF/RH pattern and takes on negative values when the bilateral pattern is more similar to the LVF/RH pattern than to the RVF/LH pattern.

The CVC bias scores were subjected to a 2 × 2 ANOVA, with gender and handedness as the between-group variables. There was no interaction between these variables, nor were the main effects significant. The mean CVC bias scores were female left-handers, .01; female right-handers, −.04; male left-handers, −.15; and male right-handers, −.06. *T* tests to check if the CVC bias score was significantly different from zero showed that this is true only for male left-handers, $t(16) = -2.21, p < .05$. That is, for these participants, the bilateral error pattern was more similar to the pattern in the LVF/RH; while for the other groups, the bilateral pattern was in between the unilateral patterns.

Table 1 presents the number of left- and right-handers and women and men who revealed asymmetry patterns implicating the LH or RH as dominant for the task. The top portion of Table 1 presents the number of individuals who revealed more errors in the LVF or RVF (interpreted as reflecting LH or RH dominance for the task). It can be seen that the majority of participants in both handedness groups made more errors in the LVF, suggesting that, for these individuals, the LH is dominant for the task. Although the proportion of left-handers who evince an atypical LVFA for the task is larger than the proportion of right-handers, this difference is not significant, $\chi^2(2, N = 94) = 2.28, p > .1$. Handedness did not affect the QE pattern (shown in the middle portion of Table 1) because the proportions of left- and right-handers who showed the typical pattern of higher QE scores in the LVF than in the RVF did not differ, $\chi^2(2, N = 94) = 1.85, p > .1$. Handedness was also independent of the direction of the CVC bias scores, $\chi^2(2, N = 94) = 1.52, p > .1$. Analyses for the effects of gender show that it too does not affect these measures.

Relations between measures. The data reported above suggest that quantitative and qualitative measures of hemispheric performance can result in different behavior patterns: There was no effect of gender, but there was an effect of handedness in the quantitative measure; whereas gender did interact with handedness and visual field in our qualitative measure. To explore these differential effects further, we computed correlations between qualitative and quantitative measures. These data are presented in Table 2. To test the internal consistency of the quantitative and qualitative asymmetry scores, we computed odd–even correlations for the visual field difference (LVF–RVF) for percentage of error scores and QE scores. The percentage of error asymmetry scores were reliable, $r(94) = .447$ (Spearman–Brown correction = .62), whereas the QE score asymmetries were less so, $r(94) = .140$ (Spearman–Brown correction = .25).

It can be seen that, with two exceptions, there are no relations between the measures. The first reveals a positive relationship between the magnitude of the quantitative performance asymmetry ($|LVF - RVF|$) and CVC bias. That is, participants who showed larger differences in overall error scores between the two visual fields tended to have a bilateral QE pattern like the RVF–LH pattern. This is true for all of the participants together, is significant for right-handers, and is in the same direction for left-handers. The second relationship is between the amount of bilateral gain and CVC bias and was significant only for left-handers. This

Table 1
Number and Percentage of Participants With Right- or Left-Visual-Field Dominance for CVC Identification

Asymmetry	Handedness: Right (n = 64)	Handedness: Left (n = 30)	Gender: Women (n = 50)	Gender: Men (n = 44)
Overall percentage of errors				
Dominant visual field				
Right	48 (75%)	18 (60.00%)	36 (72.00%)	30 (68.18%)
Left	13 (20.31%)	10 (33.33%)	10 (20.00%)	13 (29.54%)
No asymmetry	3 (4.69%)	2 (6.67%)	4 (8.00%)	1 (2.27%)
QE scores				
Visual field with larger QE score				
Right	4 (6.25%)	1 (3.33%)	1 (2.00%)	4 (9.10%)
Left	57 (89.06%)	29 (96.67%)	47 (94.00%)	39 (88.64%)
No asymmetry	3 (4.69%)	0 (0.00%)	2 (4.00%)	1 (2.27%)
CVC bias scores				
Dominant error pattern on bilateral trials				
Similar to LVF–RH	32 (50.00%)	16 (53.33%)	24 (48.00%)	24 (54.55%)
Similar to RVF–LH	29 (45.31%)	14 (46.67%)	24 (48.00%)	19 (43.18%)
Bias = 0	1 (1.60%)	0 (0.00%)	2 (4.00%)	1 (2.27%)

Note. CVC = consonant–vowel–consonant; QE = qualitative error; LVF–RH = left visual field–right hemisphere; RVF–LH = right visual field–left hemisphere.

Table 2
Correlation Coefficients Between Quantitative and Qualitative Measures in the CVC Identification Task

Quantitative measure and handedness	Qualitative measures		
	Lqe − Rqe	CVC bias	|CVC bias|
LVF–RVF			
All	−.19	.13	−.14
Right	−.08	.21	−.12
Left	−.27	−.02	−.09
|LVF − RVF|			
All	−.06	.34**	−.16
Right	−.08	.34**	−.14
Left	.05	.33	−.27
Bilateral gain			
All	.07	.08	.15
Right	.05	−.09	.21
Left	.03	.37**	.02

Note. CVC = consonant–vowel–consonant; LVF − RVF = the value and direction of performance asymmetry in total error scores (LVF = left visual field; RVF = right visual field); |LVF − RVF| = the magnitude of performance asymmetry irrespective of direction; bilateral gain = a measure of how much better performance becomes when both hemispheres receive the stimulus (computed by subtracting number of errors in the bilateral visual field (BVF) from errors in the better of the two unilateral conditions); Lqe − Rqe = the difference in qualitative error scores between the hemispheres; CVC bias = |Lqe − Bqe| − |Rqe − Bqe (an index of the similarity of the qualitative pattern of errors in the BVF to the patterns in the unilateral visual fields; a negative value indicates BVF is more like the right hemisphere, a positive value indicates BVF is more like the left hemisphere. |CVC bias| = the absolute value of CVC bias. $n = 64$ for the right-handed group and 30 for the left-handed group.
$^{**}p < .05$.

positive relationship suggests that left-handed participants who showed the most bilateral gain had a metacontrol pattern, again, more similar to the strategy of the LH than of the RH. These findings support the hypothesis that performance in the bilateral condition may reflect a pattern of interhemispheric interaction that may involve LH monitoring or rechecking of the product of RH processing of the stimulus. In general, however, differences between the hemispheres in overall ability (percentage of error scores) seem to be independent of qualitative differences in hemispheric processing strategies (QE scores).

Discussion

These data reveal three types of findings: in terms of the percentage of error scores (a quantitative measure of asymmetry), of the normalized scores (the QE scores; a qualitative measure of asymmetry), and of the relations between these measures. The quantitative measures show that, as in the report of Hellige et al. (1994), left-handers tend to have a smaller asymmetry than do right-handers. If the degree of asymmetry is an indication of the difference in ability between the hemispheres, then left-handers have more bilateral ability than do right-handers.

Patterns in the qualitative data are important in several contexts. First, we have replicated hemispheric differences in QE patterns: Our participants made more last errors than first errors in the LVF (implying a serial processing strategy) and showed a smaller difference between these errors in the RVF (implying a parallel processing strategy or more rapid distribution of attention). Second, the effects of gender and handedness in these data can help us understand the effects found in the quantitative data. Figure 2 shows that the QE scores of male left-handers (who show smaller performance asymmetries in percentage of error scores) in the LVF were significantly higher than those of right-handers, with no effects of handedness in the other visual fields. The effect is such that male left-handers make more LEs (relative to FEs) in the LVF than do right-handers. Thus, although the percentage of correct scores indicates that left-handers may have more bilateral abilities in this task (they show a smaller RVFA than do right-handers), the qualitative data pattern suggests that the difference in strategy between the two hemispheres is more extreme in left-handers than in right-handers, at least for men. As discussed by Hellige et al. (1994), the RH of left-handers does make less errors than the RH of right-handers, but this is not due to more LH-like processing in the left-hander's RH but to more efficient functioning of the RH's typical serial processing mechanism and less efficient LH parallel processing in left-handers than in right-handers.

The effect of gender occurred in the context of an interaction with handedness and visual field in the qualitative measure, where left- and right-handed men differed in the LVF (left-handed men had higher QE scores than did right-handed men), but left- and right-handed women did not differ. This effect of gender was not found by Hellige et al. (1994), so we need to be cautious in its interpretation. However, it joins a large number of reports of handedness effects in behavioral, physiological, and anatomical studies in men but not in women (e.g., Clarke et al., 1993; Clarke & Zaidel, 1994; Hellige, 1993). In addition, we found an effect of gender for right-handers only, where the QE scores of women in the two visual fields differed more than did the QE scores of men in the two visual fields. Hellige et al. found this pattern in both handedness groups in their sample.

In terms of hemispheric integration, our group data suggest that, when both hemispheres participated in the task, most women and right-handed men used a strategy that resulted in QE scores in between those shown in the unilateral conditions, whereas more of the left-handed men tended to use a strategy closer to the RH mode of processing than to the LH mode of processing. There is also a general positive relationship between the magnitude of asymmetry and CVC bias. These findings conform to those reported by Luh and Levy (1995), where individuals with larger differences between the hemispheres tended to use the LH mode of processing when stimuli were presented bilaterally and suggest that CVC bias as a measure of interhemispheric interaction may indicate more complex processes than have been previously proposed.

To summarize, the data revealed an effect of handedness, suggesting that the RHs of left-handers are more efficient than those of right-handers but not that they have more LH-like abilities. Gender effects occurred in the context of an interaction with handedness and visual field and support the conclusion that handedness may be related to brain organization differently in men and women. In general, these data replicate the findings reported by Hellige et al. (1994). More important, our measures of metacontrol suggest that there may be complex interhemispheric interactions occurring in the bilateral condition and that these warrant further study.

Experiment 2: Callosal Flexibility

To tap flexibility of callosal function, we used the letter-matching paradigm developed by Banich and her colleagues (Banich, 1995; Banich & Belger, 1990; Banich, Goering, Stolar, & Belger, 1990). Our participants matched pairs of letters either on the basis of physical or nominal identity (in different blocks). On half of the trials, the two letters that match were presented in the same visual field (within-hemisphere trials), and, on the other half, each member of a matching pair was presented to a different hemisphere (between-hemisphere trials). Banich reported that on easy or simple tasks (e.g., matching on the basis of physical identity), responses were faster on the within-hemisphere trials (a within advantage). On more difficult or complex tasks (e.g., matching on the basis of nominal identity), she reported a response time advantage for between-hemisphere trials (a between advantage). Banich proposed that the pattern on within-hemisphere trials reflects the performance of the hemisphere contralateral to the visual field in which the matching stimuli are presented. The pattern on between-hemispheres trials reflects interhemispheric interaction. She suggested that the between advantage on more difficult tasks reveals that bilateral presentation makes larger processing loads easier to handle by dispersing them across the two hemispheres. Belger and Banich (1992) have shown that the more complex the task, the larger the between advantage. We use the magnitude of the between advantage as an index of callosal flexibility. That is, by assuming that greater callosal efficiency implies better division of labor, a larger between advantage suggests more effective interhemispheric interaction. Eviatar and Zaidel (1994) have shown that the two hemispheres of split-brain participants have approximately equal ability to perform both the shape and name letter-matching tasks; so by measuring the between advantage, we have some confidence that we are tapping callosal flexibility, unaffected by relative hemispheric abilities. Banich et al. (1990) used this within–between paradigm to examine differences in callosal flexibility in left- and right-handers. They found essentially the same patterns as those reported by Banich and Belger (1990), with no differences due to handedness. However, they did not control or report effects of participant gender, which may interact with handedness.

Copeland (1995) showed that the standard Banich (1995) three-item paradigm (match a bottom lateralized stimulus to one of two top stimuli lateralized to opposite visual fields) introduces a left-to-right postexposural scanning of the top stimuli and creates an uneven perceptual load in the two hemispheres. She used a four-item paradigm instead, with two lateralized bottom stimuli and two lateralized top stimuli and peripheral cues designating the top and bottom stimuli to be compared. This eliminated the scanning, as did administering the task to native Hebrew readers (who read from right to left; Eviatar, 1995). Both these variations resulted in a between advantage, with the four-item task resulting in a somewhat smaller between advantage that the three-item task (Copeland & Zaidel, 1996). Furthermore, the four-item task showed no between advantage in a patient with an anterior callosal section, implicating anterior callosal channels in the modulation of parallel processing in the two hemispheres in the letter-matching task (Copeland & Zaidel, 1997).

The relationships between gender, handedness, and the anatomy of the corpus callosum are complex. Witelson and Nowakowski (1991), Habib et al. (1991), Clarke et al. (1993), and Clark and Zaidel (1994) reported that handedness is related to the size of the isthmus of the corpus callosum only for men (where nonright-handed men have larger corpus callosums), not for women. The behavioral effects of these differences are controversial. Potter and Graves (1988) used a variety of tasks to compare interhemispheric transfer in gender by handedness groups. They concluded that, in general, left-handers revealed more efficient callosal transfer than did right-handers, that women outperformed men in a visual transfer task, and that gender and handedness interacted in an interhemispheric texture discrimination task. However, their experiments contained only cross-field comparisons, so that baseline differences within fields were not controlled. Clarke and Zaidel looked at the relationship between the size of specific regions of the corpus callosum and behavioral asymmetries. They found a negative relationship between the size of the isthmus and the RVFA in a lexical decision task (a smaller isthmus was associated with more asymmetry) for men but not for women. Remarkably, Aboitiz et al. (1992) also showed that planum temporale asymmetries were negatively correlated with the number of small diameter fibers (interconnecting association, not sensory cortices) that cross the isthmus in men but not in women. These results converge on the conclusion that callosal morphometry indexes cognitive rather than sensory–motor traffic through the corpus callosum and that there are gender and gender by handedness effects in the organization of cognitive callosal channels. The question now is whether these effects extend to the callosal channels that permit relative hemispheric isolation and make possible parallel hemispheric processing. In this experiment, we explore whether individual differences in the magnitude of the between advantage are related to participant variables, such as gender and handedness, and to the other indices of hemispheric functioning investigated in Experiments 1 and 3.

Method

Design. The letter-matching tasks developed by Banich and Belger (1990) were used. One is a physical identity task (the shape task), and the other requires nominally identical matches (the name task). Three letters were presented on each trial: two different letters, one in each visual field, and one below them in either the

Stimuli requiring a same response in the name task

Within hemisphere conditions

Within LVF (WL)	Within RVF (WR)
a B + A	A B + b

Between hemispheres conditions

Bottom LVF (BL)	Bottom RVF (BR)
A b + B	A B + a

Figure 3. Examples of stimuli used in the within-hemisphere and between-hemispheres conditions in the letter-matching tasks. WL = within left visual field (LVF); WR = within right visual field (RVF); BL = between LVF; BR = between RVF.

RVF or LVF which matched one of the top letters, according to the appropriate decision criterion (physical identity for the shape task and nominal identity for the name task), or was different from both. Participants were to respond with *same* if the bottom letter matched either of the two top letters or *different* if all three letters were different. This resulted in four visual presentation conditions for matching stimuli: within LVF (WL), within RVF (WR), between LVF (BL), and between RVF (BR). Examples of these conditions are shown in Figure 3.

Stimuli and procedure. Each task was comprised of 160 trials. Half of these consisted of three different letters, requiring a different response, and half required a same response. There were 20 items in each visual presentation condition for matching stimuli. The letters to be matched were *D, A, T, E, F,* and *G* and their lowercase counterparts. The third letter was chosen from this set: *O, K, P,* or *S.* Only uppercase letters were used in the shape task, and both upper- and lowercase letters were used in the name task. The order of the trials and the individual letters in each trial were randomly determined for each participant. The two top letters were presented 2.80° of visual angle off fixation laterally and 1.40° above midline. The bottom letter was presented 1.40° off fixation laterally and 1.40° below midline. All the letters subtended 0.61° vertically and 0.43° horizontally. The stimuli were presented by an IBM AT computer, using a standard IBM font. On each trial, the sequence of events was as follows. A 1,000-Hz beep alerted the participants that the trial was about to begin. The fixation cross appeared for 1 s, followed by the stimulus for 150 ms. The participants were given 2 s to respond; after 1 s, the next trial began. The letters appeared in black on an orange background (reversed video). The participants were seated with their chin in a chin rest that held their eyes 57 cm from the screen. The order of the tasks was counterbalanced across individuals: Half performed the name task first and then the shape task and half, the other way round. Before each task, the participants were shown all types of presentation conditions as the task was explained and performed 40 practice trials. Within each task, the trials were presented in four blocks of 40 trials, allowing participants to rest. Each task lasted approximately 15–20 min.

Results

The comparisons of interest all involved the task by presentation condition cells. Therefore, we excluded individuals who achieved 50% accuracy scores or less in any of the task by presentation condition cells. Individuals were excluded if they achieved less than 11 correct responses in each visual presentation condition (WL, WR, BL, or BR). The analyses compared the response patterns in the within-visual-field conditions (WL and WR) with those in the between-visual-field conditions (BL and BR). Thus, all medians were based on at least 22 responses. This resulted in the inclusion of 23/36 right-handed women who participated in the task, 21/26 right-handed men, 10/13 left-handed women, and 11/15 left-handed men. A chi-squared analysis of these inclusion rates revealed that they were independent of handedness or gender, $\chi^2(3, N = 90) = 2.34, p > .5$.

The median response times (RTs) and percentage of error scores were analyzed separately with a four-way ANOVA, using gender and handedness as the between-groups variables and task (name vs. shape) and visual field condition (within vs. between) as the within-subject variables. The RT analysis revealed a main effect of task, $F(1, 61) = 132.48$, $p < .0001$, with responses for the name task ($M = 735$ ms) slower than those for the shape task ($M = 607$ ms); a main effect of visual field condition, $F(1, 61) = 18.21, p < .0001$, with between-visual-field conditions ($M = 658$ ms) faster than within-visual-field conditions ($M = 685$ ms); and a Handedness × Visual Field Condition interaction, $F(1, 61) = 5.15$, $p < .05$, where right-handers showed a significant between advantage, $F(1, 42) = 29.62$, $p < .0001$, and left-handers did not ($p > .5$). This interaction is illustrated in Figure 4. No other effects approached significance.

Analyses of the handedness groups separately revealed that the expected Task × Visual Field Condition interaction was significant for right-handers, $F(1, 42) = 12.22$, $p < .005$, with a large between advantage in the name task (between = 694 ms vs. within = 753 ms) and a smaller between advantage in the shape task (between = 588 ms vs.

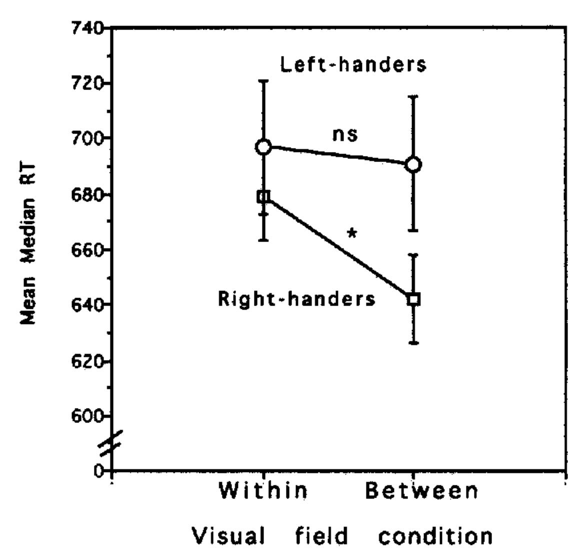

Figure 4. Interaction of handedness and visual presentation condition in the letter-matching task. Right-handers show a significant between advantage; left-handers do not. RT = response time; ns = nonsignificant. *$p < .05$.

within = 605 ms). This interaction was not significant for left-handers ($p > .6$), although the between advantage was larger in the name task (between = 754 ms vs. within = 765 ms) than in the shape task (between = 627 ms vs. within = 629 ms).

The analysis of percentage of errors revealed a main effect of task, $F(1, 61) = 153.89$, $p < .0001$, with more errors in the name task ($M = 24\%$) than in the shape task ($M = 12\%$); and a main effect of visual field condition, $F(1, 61) = 16.44$, $p < .0001$, with more errors in the within-visual-field condition ($M = 19.85\%$) than in the between-visual-field condition ($M = 16.16\%$). No other effects were significant.

Odd–even reliabilities were computed on the response time and error scores in each task separately. These are presented in Table 3. The reliabilities within each visual presentation condition were high, and the reliabilities of the between advantage were low. This is due to high correlations between the within-visual-field and between-visual-field conditions, which reduced the variance of the difference scores.

Discussion

In general, our results replicate those reported by Banich and Belger (1990) and by Banich et al. (1990). In the more difficult or complex name task, performance was faster when the stimuli that matched were presented each to a different hemisphere, thus reflecting an advantage of load sharing, whereas on the easier or simpler shape task, there was a smaller difference between the presentation conditions. Banich and her colleagues usually found a small within advantage in the shape task and interpreted this as an indication of the costs of callosal transfer in this easy task. One possible explanation for the discrepancy between our findings and those of Banich and her colleagues in the shape task may be methodological. Our exposure duration was shorter than the one used by Banich and Belger (150 ms vs. 200 ms). This resulted in both tasks being more difficult in our experiment (as reflected by the exclusion rates). Both our tasks revealed an advantage for the between-visual-fields conditions, but this advantage was smaller in the shape task, presumably because the advantage conferred on performance by dividing the labor between the hemispheres in the shape task was not crucial, as it was in the more difficult name task.

Our RT findings support the hypothesis that left-handers have less flexible callosal function than do right-handers because the between advantage is smaller in this group. This finding of an interaction of handedness with visual field condition differs from that reported by Banich et al. (1990), who reported no effects of handedness on the between advantage. In that study, Banich et al. used a digit-matching task and a spelling task as the easy and difficult tasks and analyzed the mean RT from four levels of the visual field conditions. Thus, the studies differ in three ways: tasks (letter matching vs. digits and spelling), dependent measure (median RT vs. mean RT), and manner of slicing the visual field conditions (two conditions vs. four conditions). We reanalyzed our data, using all four visual field conditions with medians as the dependent variable, and, in a separate analysis, using mean RTs. In both analyses, the interaction between handedness and visual field was not significant ($p > .1$). We believe that the use of median RTs and a reduction of the visual field conditions to within versus between is a more straightforward way to isolate the between advantage as a measure of callosal efficiency. Thus, the discrepancy between our results and those of Banich et al., we believe, are due to the use of medians (which are the preferred RT measure because they are less influenced by outliers) rather than means and to the manner in which the between advantage shows up when data are summed over the within- and between-visual-field conditions. It may also be the case that the type of tasks affected the results.

As mentioned in the beginning of this article, Potter and Graves (1988) found differences among their participant groups when they only compared cross-field conditions. To see if individual differences only occurred in the cross-field conditions, we analyzed the RT and error data from the within and between conditions separately. Neither analysis resulted in effects of gender or of handedness. This suggests that the groups did not differ in hemispheric capacity for the tasks and strengthens the hypothesis that left-handers differ from right-handers in the efficiency with which their hemispheres communicate with or shield each other, not in the abilities of the hemispheres to perform the letter-matching tasks.

The definition of the between advantage as a measure of the flexibility of hemispheric interaction is based on the finding that it is larger for more cognitively complex tasks than for simpler tasks. If an individual difference (e.g., handedness) affects callosal flexibility, by a strict criterion we expect to find a Handedness × Task × Visual Field (within–between) interaction. Although the Task × Visual

Table 3
Reliability Coefficients for the Letter-Matching Tasks

Task	Within-condition split half	Between-condition split half	Between-advantage split half	Within and between
Name				
Response time	.855 (.92)	.905 (.95)	−.040 (−.08)	.860
Errors	.140 (.25)	.050 (.10)	−.070 (−.12)	.310
Shape				
Response time	.870 (.93)	.869 (.92)	.120 (.21)	.920
Errors	.590 (.74)	.580 (.73)	.450 (.62)	.530

Note. $N = 65$. Spearman–Brown correction is in parentheses.

Field interaction was significant for right-handers but not for left-handers, the three-way interaction was not significant ($p = .12$). However, if we loosen the criterion and take the magnitude of the between advantage as an index of the flexibility of interhemispheric interaction overall, we have shown an effect of handedness on this measure.

Because this three-item paradigm introduces postexposural scanning, it is possible to compute the between advantage for the two conditions that do not involve scanning, that is, where the top matching stimulus is in the LVF (WL and BR conditions; see Figure 2). An analysis of latency using only these two conditions revealed the usual advantage of shape over name, $F(1, 61) = 82.49, p < .0001$; a significant between advantage (BR vs. WL), $F(1, 61) = 17.25, p < .0001$; and the Expected Task × Visual Field Condition interaction, $F(1, 61) = 8.20, p < .01$. As in the previous analysis, handedness interacted with visual field, $F(1, 61) = 4.74, p < .05$. The three-way interaction between handedness, task, and visual field approached significance, $F(1, 61) = 3.5, p = .07$, with right-handers showing a large between advantage for the name task (66 ms) and a smaller one for the shape task (24 ms) and left-handers showing a minimal difference (8 ms for name and 7 ms for shape). In addition, there was also a significant Gender × Visual Field interaction, $F(1, 61) = 4.81, p < .05$. Women had a smaller difference between WL and BR (670 ms vs. 654 ms) than did men (693 ms vs. 642 ms). There was no main effect of gender, nor did it interact with any other variable. Given that this effect did not show up in the original analyses using all of the data and the lack of a Gender × Task × Visual Field interaction, we are cautious in interpreting this finding as evidence for a gender effect in callosal flexibility measured on this task. More definite resolution of the gender difference in the between advantage requires administration of Copeland's (1995) four-item task to men and women. In summary, the data revealed an effect of handedness, with left-handers evincing less flexible callosal function than do right-handers, and no effects of gender.

Experiment 3: Hemispheric Arousal Bias

To tap hemispheric arousal bias, we used the chair identification task developed by Levine and her colleagues (Kim, Levine, & Kertesz, 1990; Levine, 1995; Levine, Banich, & Koch-Weser, 1984). Participants were presented with two different stimuli (one to each hemisphere) on every trial and then were asked to identify both stimuli among an array of 12 possibilities. The experimental procedure was such that exposure duration was titrated to give participants enough time to correctly identify only one of the pair of stimuli (chairs, i.e.). Under normal circumstances, there is no visual field advantage for identifying chairs. Levine and her colleagues have reported that the asymmetry between correctly reported LVF and RVF stimuli is normally distributed among right-handers and is correlated with the magnitude of visual field advantages for other tasks. That is, this asymmetry is interpreted as reflecting a bias of attention to one visual field over the other, which is thought to contribute to visual field advantages for all tasks including those that usually result in perceptual asymmetries. Kim et al. reported that 45.2% of the variability in asymmetry scores on a variety of lateralized tachistoscopic tasks and on a free vision chimeric faces task is attributable to variance in characteristic arousal asymmetry (as measured by the chair task) and that this value does not differ for left- and right-handers. They reported an interesting interaction with gender, where men with a larger bias toward the RH revealed a larger LVFA for tachistoscopic faces than men with a bias toward the LH, but women with opposing biases did not differ. Thus, they have shown that, for men at least, characteristic arousal asymmetry is related to the performance asymmetry in a task for which the RH is more capable. Our experiment tested whether left- and right-handers differed as a group in their general distribution of arousal asymmetry and whether there is a relationship between degree and direction of arousal asymmetry and callosal efficiency, as measured by the letter-matching task, and hemispheric strategies, as measured by the CVC letter identification task.

Method

The chair identification task developed by Levine et al. (1984) was used. Our participants were presented tachistoscopically with pictures of two different chairs, one in each visual field. They then attempted to identify these chairs in an array of 12 chairs, seen in free vision. The stimuli and procedure were identical to those reported by Levine et al., except that both stimulus presentation and response collection were done by a MacII computer. The photographs of chairs used by Levine et al. were scanned and digitized and presented on a gray background. The stimulus chairs were shown with their inner edge 2.00° of visual angle from fixation and subtended 1.88° horizontally and 2.45° vertically. To maximize hemispheric competition, we titrated exposure duration in 15-ms increments after each trial. Initial exposure duration was 60 ms. If the participant misidentified both chairs, the next stimulus pair was shown for 15 ms longer, up to a maximum of 210 ms. If they correctly identified both chairs, the exposure duration of the next pair was 15 ms shorter. Exposure duration remained the same if one chair was correctly identified. The dependent variable was the number of chairs correctly identified in the LVF minus the number identified in the RVF. Participants completed 12 practice trials and then the 20 experimental trials.

Results

The data from the chair identification task were analyzed using a 2 × 2 ANOVA for unequal groups, with handedness and gender as the grouping variables. The data were collected from 36 right-handed women, 29 right-handed men, 14 left-handed women, and 17 left-handed men. The dependent measure was number of chairs correctly identified from the LVF minus number identified from the RVF. Thus, a negative number indicates higher arousal in the LH and a positive number indicates higher arousal in the RH. The ANOVA revealed only a main effect of handedness, $F(1, 92) = 7.15, p < .01$. The right-handers had a mean score of −0.138, which is not significantly different from 0 ($p > .5$). The left-handers had a mean score of 1.870. This bias toward the RH was significantly different from 0,

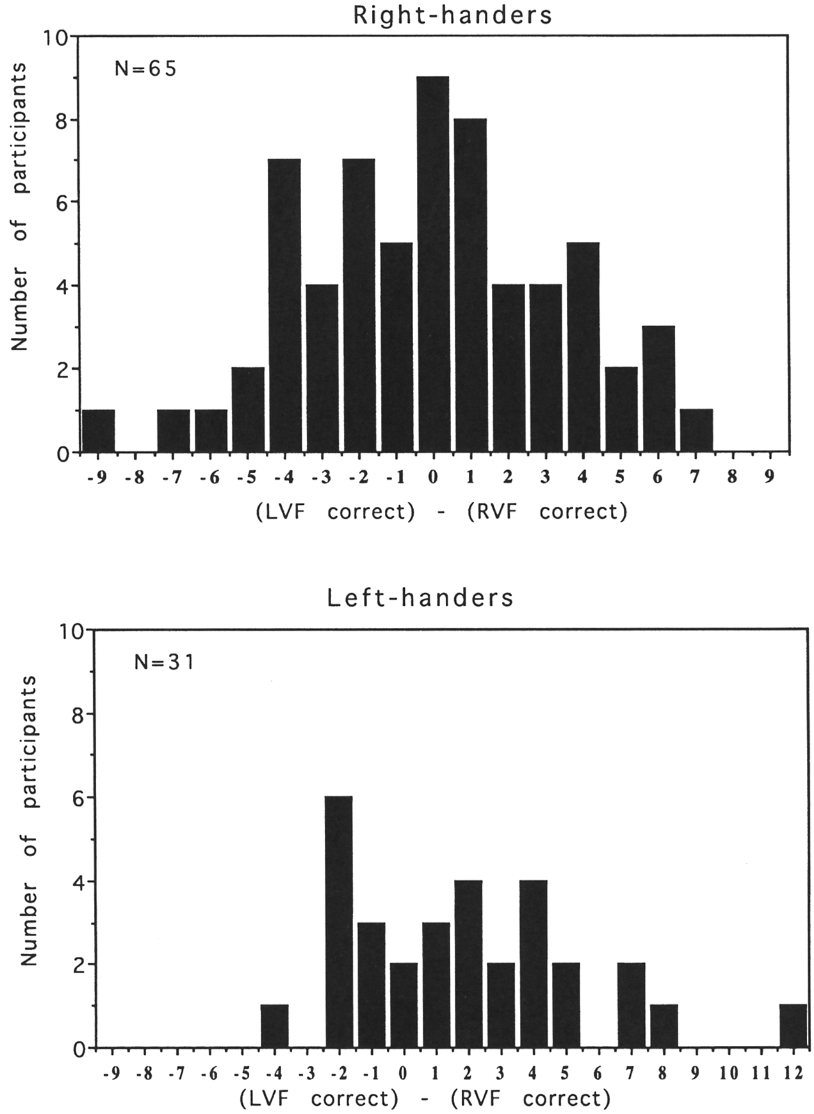

Figure 5. Distribution of visual field difference scores in the chair identification task for left- and right-handers. Negative scores indicate that more chairs were correctly identified in the right visual field (RVF) than in the left visual field (LVF), reflecting a more aroused left than right hemisphere. Positive scores indicate that more chairs were correctly identified in the LVF than in the RVF and reflect a more aroused right than left hemisphere.

$t(30) = 2.88$, $p < .01$. A test for equality of variances revealed that they did not differ in the handedness by gender groups, $\chi^2(3, N = 96) = 0.23$, $p > .5$. The distributions of scores for right- and left-handers are shown in Figure 5. A test of the reliability of these scores was done by computing odd–even correlations for the difference between LVF and RVF scores. The correlation was significant although low, $r(91) = .21$ (Spearman–Brown correction = .35).

Discussion

The data of the right-handers replicate the findings of Kim et al. (1990) and Levine et al. (1984). There is no evidence of hemispheric specialization for the task, and the visual field difference scores are normally distributed around zero. The data of the left-handers suggest that they tend to have more aroused RHs than LHs.[1] This contradicts the hypothesis of Kim et al. that arousal asymmetry is distributed in the population independently of handedness. However, given the relatively small number of left-handed individuals and the relatively low reliability index, we are cautious in interpreting these results.

[1] We excluded the male left-hander who had the most extreme asymmetry score (+12) and reanalyzed the data. The results did not change: The main effect of handedness was significant, $F(1, 90) = 4.90$, $p = .029$, and the mean of the left-handers (1.496) was significantly different from 0, $F(1, 90) = 5.90$, $p = .017$.

Intertask Analyses

One of the goals of these experiments was to explore the possible relationships between the components of performance asymmetry (hemispheric abilities, callosal flexibility, and arousal bias). For example, left-handers as a group showed better CVC identification in the LVF than did right-handers as a group. They also showed evidence for less efficient callosal functioning on the letter-matching task and for higher RH arousal on the chair task. We may therefore expect to see a correlation between performance asymmetries on these tasks. We explored the relations between the tasks in two ways: First, we divided the participants according to their scores on the chair identification task (into LH biased, unbiased, or RH biased groups); second, we looked at correlations between the scores on the tasks.

Grouping Variables

Following Kim et al. (1990), we divided the participants into three groups by their chair identification scores. The participants were classified as LH biased or RH biased if their chair asymmetry score was more than 1 *SD* under (for the LH bias group) or over (for the RH bias group) 0. The prediction (following Kim et al.'s) is that individuals who differ on characteristic arousal asymmetry (as indexed by the chair task) may differ in the performance patterns they evince in the other tasks. For the individuals who participated in both the CVC identification task and the chair task, this resulted in 12 LH biased participants, 19 RH biased participants, and 59 unbiased individuals. This grouping factor was included in separate analyses of percentage of error asymmetries, bilateral gain, QE scores, QE asymmetries, and CVC bias. The only analysis that revealed an effect of chair grouping was of QE asymmetry (Lqe − Rqe), $F(2, 66) = 3.83, p < .05$, where unbiased individuals (those with a chair asymmetry score within 1 *SD* of 0) have the smallest QE asymmetry ($M = 29.58$), RH biased individuals have the largest QE asymmetry ($M = 41.22$), and LH biased individuals have an intermediate score ($M = 31.58$). Planned comparisons revealed that individuals with an RH bias on the chair task had a significantly larger difference in QE scores between their hemispheres than did the other two groups, while LH biased and unbiased participants did not differ from each other. No other analysis revealed significant effects or interactions with chair grouping.

Classification of the individuals who had participated in both the letter-matching and chair tasks resulted in 7 individuals classified as LH biased, 16 classified as RH biased, and 35 classified as unbiased. We analyzed the degree of between advantage (within visual field–between visual field) using a 3 × 2 ANOVA, with chair grouping and task (shape vs. name) as independent factors. The main effect of chair grouping was not significant, nor did it interact with the task.

Correlations

We computed correlations between the various measures in the three experimental tasks. These are presented in Tables 4 and 5. Table 4 presents the correlations between performance asymmetry on the chair task and various measures from the letter-matching and CVC identification tasks. Table 5 presents the pairwise correlations between measures in the CVC and letter-matching tasks. The most salient aspect of these matrices is the lack of significant relationships. However, these null findings must be seen in the context of the low reliabilities of several of the difference measures. For example, the between advantage (RT within–RT between) from Experiment 2 had a low reliability index, as did the arousal measure (LVF correct–RVF correct) from Experiment 3. This is due to a general problem with difference scores, where high correlations between the elements that make up the difference score reduce its variance and the correlation measure. Only one relationship was significant for the sample as a whole, a negative correlation between the between advantage for errors on the shape task (Experiment 2) and CVC bias (Experiment 1). This relationship suggests that individuals with a larger

Table 4
Pairwise Correlations Between Asymmetry Scores on the Chair Identification Task and Various Measures on the Letter-Matching and CVC Identification Tasks

Measure	Chair identification task: Participants	*n*	LVF − RVF
Letter identification task (by name)			
Callosal efficiency			
Response time	All		−.050
	Right-handers	37	.190
	Left-handers	21	−.110
Errors	All		.070
	Right-handers	37	−.060
	Left-handers	21	.230
Letter identification task (by shape)			
Callosal efficiency			
Response time	All		.060
	Right-handers	37	.002
	Left-handers	21	.290
Errors	All		−.160
	Right-handers	37	−.290
	Left-handers	21	.170
CVC identification task			
Quantitative measures			
LVF − RVF	All		−.060
	Right-handers	60	−.040
	Left-handers	30	.060
Bilateral gain	All		.150
	Right-handers	60	.120
	Left-handers	30	.130
Qualitative measures			
Lqe − Rqe	All		.190[a]
	Right-handers	60	.200
	Left-handers	30	−.020
CVC bias	All		−.080
	Right-handers	60	.050
	Left-handers	30	−.100

Note. CVC = consonant–vowel–consonant; LVF − RVF = left visual field − right visual field; Lqe − Rqe = the difference in qualitative errors between the hemispheres.
[a] $p = .074$.

Table 5
Pairwise Correlations Between Measures on the CVC Identification and Letter Identification Tasks

		CVC identification task			
		Quantitative measures		Qualitative measures	
Callosal efficiency	Participants	LVF − RVF	Bilateral gain	Lqe − Rqe	CVC bias
		Letter identification task (by name)			
Response time	All	.06	−.07	−.20	−.08
	Right-handers	−.16	−.13	−.20	−.10
	Left-handers	.16	.18	−.05	−.02
Errors	All	.07	.07	−.02	−.03
	Right-handers	.03	.17	.21	−.37
	Left-handers	.15	−.08	−.42*	−.37
		Letter identification task (by shape)			
Response time	All	−.04	.06	−.04	−.09
	Right-handers	−.07	−.03	−.06	−.12
	Left-handers	−.08	.27	.10	−.03
Errors	All	.05	−.07	.10	−.28**
	Right-handers	.19	−.06	.33*	−.37**
	Left-handers	−.23	−.03	.25	−.13

Note. CVC = consonant–vowel–consonant; LVF − RVF = left visual field − right visual field; Lqe − Rqe = the difference in qualitative errors between the hemispheres.
$*p < .06$. $**p < .05$.

between advantage (more flexible callosal function) have an error pattern in the BVF condition of the CVC experiment, which is more like the pattern in the LVF–RH than in the RVF–LH. This effect was also significant in the right-handed sample but not in the left-handed sample. Several other relationships approached significance. However, given the context of many nonsignificant coefficients and low reliabilities, these results must be treated with caution and replicated before we can interpret them.

General Discussion

The intertask analyses were performed to investigate the relationships between callosal flexibility, quantitative and qualitative differences in hemispheric performance, and arousal bias. Using direction of arousal asymmetry as a grouping variable on our measures of hemispheric differences in processing strategy (the difference between QE scores in the LVF and RVF in the CVC task) revealed a relationship between the existence of bias and hemispheric processing differences. The effect is such that individuals with approximately equal arousal levels in the two hemispheres or LH arousal bias evince smaller hemispheric differences than do participants with RH arousal bias. Recall that the interaction between handedness and visual field in QE scores was significant for men, with left-handers evincing higher QE scores than did right-handers in the LVF, and the groups not differing from each other in the other visual fields. Recall also that left-handers as a group revealed higher RH than LH arousal on the chair task. Thus, the data suggest that these two elements of performance asymmetry (hemispheric ability and arousal bias) are not independent of one another, at least for men. This effect was not significant in the correlation analysis, although it approached significance for the sample as a whole, $r(89) = .19, p = .074$. The only relationship that was significant for the sample as a whole, and for right-handers, was between the error measure of callosal flexibility in the shape task and CVC bias. CVC bias is an index of interhemispheric integration that must rely on callosal connectivity. Therefore, it may make sense that these measures are related, as both index an aspect of callosal connectivity. In general, the dearth of intertask correlations may be a theoretically important finding, but it must be interpreted cautiously because it may be an artifact of the low reliabilities of difference scores.

Conclusions

Our results speak to two separate questions. First, we wanted to investigate the effects of gender and handedness on performance in tasks that rely primarily on different aspects of hemispheric functioning. The results of the letter-matching task (measuring interhemispheric flexibility) suggested that left-handers have less flexible callosal function than right-handers and revealed no effects of gender. The CVC identification task (measuring hemispheric ability) revealed interesting effects of both gender and handedness. The quantitative measures of hemispheric abilities showed that left-handers have smaller performance asymmetries than do right-handers and constituted a replication of previous findings (Hellige et al., 1994). The qualitative measures suggested that this is due to more efficient RH functioning in left-handers than in right-handers, although the strategy remains distinctly right hemispheric. Effects of gender in this task appeared only in the context of handedness and visual field, where left-handed men seemed to use the serial processing mode that resulted in large QE scores more than did the other groups in the LVF.

The data patterns on the chair identification task (measuring arousal bias) suggested that our group of left-handers included more individuals with more aroused RHs than LHs. These data differ from those reported by Kim et al. (1990), who found no differences between handedness groups, and need to be replicated. We found no effects of gender in this task.

A summary of the effects due to gender and handedness in the three tasks is shown in Table 6. It is interesting to note that there was no main effect of gender in any of the tasks. Effects of gender appeared only in the qualitative measures of the CVC task and interacted with handedness (handedness affected the performance of men, not of women). These data suggest that handedness has a more potent effect on hemispheric and interhemispheric functions than does gender and that handedness is not related to hemispheric organization in the same way in men as in women.

The intertask analyses were performed to look at the relationships among callosal flexibility, hemispheric abilities, and arousal bias. Using the chair asymmetry score as a grouping variable reveals that individuals with more aroused RHs than LHs have a larger processing difference between their hemispheres (a larger difference between the QE scores in the LVF and the RVF) than do individuals with more equally aroused hemispheres or more aroused LHs. This effect approached significance in the correlation analysis and may have been limited by the reliability problems of the difference scores. The correlation analyses revealed only one significant relationship, between a measure of callosal flexibility (the between advantage for errors in the letter-matching shape task) and the measure of metacontrol in the CVC task (CVC bias). However, CVC bias did not correlate with measures of callosal flexibility in the name task or with bilateral gain for right-handers in the CVC task. All of these indices measure interhemispheric interaction, so that we would expect significant relationships to emerge. The finding that only CVC bias and error scores on the shape task are related may be due to several sources: (a) the restricted variance of difference scores that is reflected in the reliability measures (of all the measures except error scores in the shape task) or (b) these measures index different callosal functions that may be subserved by different channels, which may be more or less independent of each other.

To summarize, we have explored the effects of participant variables, such as gender and handedness, on three different aspects of performance asymmetry. Our results showed that handedness affects all three aspects (hemispheric abilities, callosal flexibility, and arousal asymmetry), while gender does so only in the context of handedness. Left-handers showed smaller performance asymmetries on the CVC task, less flexible callosal function on the letter-matching task, and more aroused RHs on the chair task. However, the intertask analyses (although limited by the low reliabilities) suggest that it is not generally the case that participants with more bilateral hemispheric abilities on the CVC task (Experiment 1) are the ones with more or less flexible callosal function as indexed by the letter-matching tasks (Experiment 2) or are those that have a particular pattern of hemispheric arousal bias in the chair task (Experiment 3).

Table 6
Summary of Effects of Gender and Handedness in the Three Tasks

Component of performance asymmetry	Participant characteristic		
	Gender	Handedness	Gender × Handedness interaction
Callosal connectivity			
Accuracy	–	–	–
Speed	–	+	–
Hemispheric abilities			
Quantitative	–	+	–
Qualitative	–	+	+
Arousal asymmetry	–	+	–

Note. – = lack of effect.

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