The Cerebral Laterality of Mental Image Generation in Normal Subjects

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ABSTRACT

This research was an attempt to replicate and extend a published study that reported a left hemispheric locus for the generation of mental images. Several methodological problems were addressed, the stability of effects was assessed by repeating the experiment, and P300 latency was measured. A lateralized visual choice reaction time task was performed twice, once without the use of imagery and once with imagery. In each visual field, the use of imagery produced a speeding of reaction times when the target stimuli matched the image generated by the subject. A similar effect was present for P300 latency, and was still present in the reaction time data after partialling out the P300 latency effect. These results indicate that mental imagery can speed both stimulus evaluation and response processing. There was no difference in the amount of speeding for images in the two hemifields, providing no evidence for a preferential locus of mental image generation in either cerebral hemisphere.

DESCRIPTORS: Visual imagery, Cerebral laterality, P300, Reaction time.

During the last two decades, there has been a resurgence of interest in mental imagery. In cognitive psychology, much debate has centered on the properties of mental imagery, its relationship to perception, and its underlying mental representations (see Finke, 1985; Kosslyn, 1981; and Pylyshyn, 1981). In the field of health, mental imagery's capacity for inducing physiological changes and its relationship to psychosomatic illnesses have been demonstrated (Sheik & Kunzendorf, 1984). However, mental imagery has been relatively ignored in studies on the laterality of cerebral function. Because of its quasi-perceptual and subjectively spatial nature, many have implicitly assumed that mental imagery is a function of the right hemisphere. In their review of the literature on this topic, Ehrlichman and Barrett (1983) concluded that there was insufficient evidence to support this assumption. Most of the studies they examined had results consistent with a bilateral involvement in mental imagery. Moreover, recent studies of brain-damaged patients have emphasized a left hemisphere capacity to generate mental imagery (Farah, 1984; Farah, Gazzaniga, Holtzman, & Kosslyn, 1985; Kosslyn, Holtzman, Farah, & Gazzaniga, 1985).

A provocative study of normal subjects by Farah (1986) also implicated the left hemisphere in the generation of mental imagery. In a choice reaction time study, subjects determined whether a briefly presented lateralized stimulus belonged to a target stimulus set. The task was performed twice. In the baseline condition, subjects simply executed the task, without using any mental imagery. In the imagery condition, before each trial, subjects were cued to create a mental image of one of the target stimuli in the area of the visual field where the subsequent stimulus would appear. It was hypothesized that this image could be used as a template to facilitate stimulus evaluation, especially when the image and subsequent stimulus were the same. This was expected to produce faster reaction times that those recorded in the baseline condition. Hemispheric specialization for mental image generation was inferred from a faster reaction time for an image generated in one visual hemifield than the other. The results of the study indicated a greater reduction in reaction time for right hemifield images, suggesting a left hemisphere locus for mental image generation (Farah, 1986).

There were methodological problems in Farah's study that may have influenced the outcome. First, although subjects were instructed to focus on a central fixation point during each trial, eye position and eye movements were not monitored. There-
fore, her findings may have resulted from prefer-
etial gaze or eye movements toward one hemifield
during the imagery condition. Second, all of the
study subjects performed the task under the bas-
line condition followed by the imagery condition,
and order effects were confounded with the base-
line-imagery comparison. Farah ran the experiment
in this order because pilot subjects reported a tend-
ency to continue imaging when the imagery con-
dition preceded the baseline condition. Third, the
study was biased toward finding an effect of imagery
because subjects who did not have a shortened re-
action time in the imagery condition were excluded
from the analysis.

This manuscript describes a replication and ex-
tension of Farah's study, addressing the above men-
tioned issues. Eye position was carefully monitored
via video-camera and eye movements were meas-
ured, with elimination of suspect trials. The order
of presentation of the baseline and imagery con-
ditions was counterbalanced with no subject re-
porting imagery in the baseline condition. Data
from all subjects who successfully completed the
experiment were included in the primary data anal-
yses, irrespective of whether they had an imagery-
associated decrease in reaction time. The stability
of experimental effects was assessed by repeating
the experiment in a second session in 90% of the
subjects. Finally, because midline P300 latency has
been shown to reflect stimulus evaluation time, re-
gardless of the sensory modality or hemisphere of
stimulus presentation (McCarthy & Donchin, 1981;
Magliero, Bashore, Coles, & Donchin, 1984), the
evoked potential was recorded and P300 latency was
determined in an attempt to partition any de-
crease in reaction time associated with imagery into
stimulus evaluation and response processing com-
ponents.

Methods
Overview

The experimental paradigm consisted of a visual
choice reaction time task, with hemifield stimulus
presentation. Two stimuli had been previously des-
ignated as targets and four as nontargets. The task was
performed twice, once without the use of imagery
(baseline condition), and once with imagery (imagery
condition). In both conditions, during the prestimulus
period, subjects were cued as to the hemifield of stimu-
lus presentation. In the imagery condition, subjects
were presented with one of the targets in addition to
the position cue and were instructed to image this tar-
get in the position of the upcoming stimulus. Subjects
were instructed to respond to both target stimuli as
targets, whether or not the presented target matched
the one they imaged.

To ensure that stimuli were presented to the ap-
propriate hemifield, eye position was monitored via
video camera and eye movements via electro-oculo-
gram. The electroencephalogram was recorded during
the experiment, and the latency of the P300 compo-
nent of the evoked potential was used as a measure of
stimulus evaluation time.

Subjects

Eight males and 14 females, aged 23–46 years, were
studied. All subjects were right-handed (average score
+93, range +73–100) as assessed by the Edinburgh
Inventory (Oldfield, 1971). All 8 males and 12 of the
14 females were retested during a second session which
in all cases was at least one month after the initial
testing session.

Stimuli

Stimuli were generated by an IBM compatible
80386 computer and displayed on a Sony Multiscan
monitor. Because electromagnetic radiation from the
computer monitor interfered with EEG recording with
subjects seated 12 inches from the screen (as in Farah's
(1986) experiment), subjects were seated 36 inches from
the display screen. The physical size of the stimuli was increased to yield stimuli that were the
same size and location in the visual field. Throughout
the experiment, the stimulus display included a verti-
cal "pipe" symbol ( ) in the center (the break in the
middle of the "pipe" symbol was designated as the
fixation point) and markers (consisting of a pair of
underscore characters separated by a space) which de-
lineated the stimulus positions 3 degrees to the
right, left, above, and below the fixation point. The stimuli appeared in the space between the underscore characters and sub-
tended an angle of .375 degrees horizontally, and be-
tween .063 and .627 degrees vertically. The stimulus
consisted of two targets: a plus sign (+) and a zero
(0), and four nontargets: an asterisk (*), a minus sign
(−), a capital O, and an "at" sign (@). These targets were
presented equally often. Hemifield of stimu-
lation was also randomized. Data were
there were at least 32 good trials in each
category. A trial was considered good if
response was a hit or if the subject was not contaminated by eye
n
For each condition, subjects received
practice session prior to the start of t-
ner. Half of the subjects completed the bas-
line condition first, and the other half
completed the experiment in the rever-
ses of these subjects reported continuing
hemifield of stimuli seen during the
preceding condition. All subjects reported
stimuli were presented to the appro-
appropriate hemifield, eye position was monitored via
video camera and eye movements via electro-oculo-
gram. The electroencephalogram was recorded during
the experiment, and the latency of the P300 compo-
nent of the evoked potential was used as a measure of
stimulus evaluation time.

Subsequently, all of these subjects reported
continuing to image the stimuli with the same inten-
tion as their baseline imagery condition.

It is important to note that accurate
video screen stimuli are complicated by the
hardware of the video monitor. For exam-
ple, the monitor may not always display the
video area accurately. On some occasions, the
video image may be displaced on the monitor,
resulting in a slight misalignment of the stimuli.
However, this does not affect the overall per-
formance of the subjects, as the stimuli remain
accurate within the limits of the video display.
Stimuli were generated by an IBM compatible computer and displayed on a Sony Multiscan Electronic CRT as assessed by the Edinburgh Handedness Inventory (1971). All 8 males and 12 of the females aged 33–46 years were seated at a table and they controlled stimulus presentation using a foot pedal. Responses were generated equally often. Hemisphere of stimulus presentation was randomized. Data were collected until there were at least 32 good trials in each stimulus category. Equal numbers of targets and nontargets were presented, and within each of these categories, each stimulus was presented equally often. Hemifield of stimulus presentation was also randomized. Data were collected until there were at least 32 good trials in each stimulus category. A trial was considered good if the subject responded correctly to the stimulus and the evoked potential was not contaminated by eye movements.

For each condition, subjects received a 32-trial practice session prior to the start of data collection. Half of the subjects completed the baseline condition followed by the imagery condition. The other half completed the experiment in the reverse order. None of these subjects reported continuing to image in the baseline condition. All subjects reported following the imaging instructions at least 75% of the time.

In order to determine the stability of a subject's responses across time, all of the subjects were asked to return and repeat the experiment. It was possible to gather repeat data for 20 of the 22 subjects. For each subject, order of condition presentation and target response hand were the same on the repeat experiment as on the initial experiment.

Evoked Potential Recording

Evoked potentials were recorded with gold cup electrodes placed at Pz and C3 referenced to the left ear. Electro-oculogram (EOG) was recorded between electrodes positioned below the outer canthus of the left eye and above the outer canthus of the right eye. The signals were amplified with a Grass Model 7B polygraph (60 Hz filter, band pass = .1–35 Hz). Electrode impedances were kept below 5 K ohms. The signals were digitized and averaged on-line at a sampling rate of 250 Hz per channel. Sampling began at stimulus presentation and continued for 1000 ms. Any epoch contaminated by significant EOG artifact (signal excursion greater than 60 microvolts) was automatically rejected, as were epochs associated with incorrect or missing responses.

Results

Reaction Time Data

The target stimuli trials were separated according to whether the target matched the imaged stimulus (similar image targets) or did not match the imaged stimulus (dissimilar image targets). The target reaction times were then analyzed using a 3(Condition: baseline, similar image, dissimilar image) × 2(Visual Field: left vs. right) × 2(Order: baseline first vs. imagery first) multivariate analysis of variance (MANOVA) for repeated measures designs. The analysis was implemented using the PC/SAS General Linear Models procedure. The input to the analysis consisted of the median reaction time for each subject for each condition × visual field condition. Medians were used because they are more resistant to the effects of outlier observations. Table 1 presents these reaction time data.

The statistically significant findings were a Condition × Order interaction (F(2/19)= 9.80, p = .001) and a main effect of Condition (F(1/19)= 13.83, p = .0002). There was a trend for a main effect of Order (F(1/20)= 2.95, p = .10), with reaction times from subjects receiving the baseline condition first tending to be faster overall than reaction times from subjects receiving the imagery condition first. There was no evidence for a main effect of Visual Field (F(1/20)= .03) or for a Visual Field × Condition (F(1/19)= .29, and F(1/20)= 1.54, respectively). Finally, the three-way interaction was nonsignificant.

The Condition effect was then partitioned into two 1-degree-of-freedom contrasts: baseline vs. similar image targets, and similar vs. dissimilar image targets. When Order was included in the MANOVA
model, median reaction times to similar image targets were faster than to baseline targets \((F(1/20)=4.85, p=.04)\), and there was a highly significant Condition \(\times\) Order interaction \((F(1/20)=18.92, p=.0003)\). There was both a very strong practice effect resulting in faster reaction times in the second condition compared to the first and a smaller condition effect with faster reaction times in the similar image compared to the baseline condition. The results for the similar image target vs. dissimilar image target were also illuminating. With Order included in the MANOVA model, median reaction times to similar image targets were much faster than those to dissimilar image targets \((F(1/20)=28.00, p=.0001)\), and again, there was a significant interaction with Order \((F(1/20)=4.98, p=.04)\). These results indicate that the large reaction time decrease for similar image targets compared to dissimilar image targets are slightly larger when the imagery condition comes second, possibly as a result of the subject having had practice with the task.

The above analyses included data from some subjects who did not show the predicted imagery effects of decreased reaction times on trials with matching images and target stimuli. In her experiment, Farah (1986) eliminated the data from such subjects and replaced them with new subjects. To determine whether the differing results of the current experiment could be due in part to the inclusion of such subjects, a separate analysis was performed only on data from subjects \((N=17)\) who had faster reaction times for similar compared to dissimilar image targets. The results of this analysis were virtually identical to those presented above for all subjects. There was no evidence for a main effect of Visual Field or a Visual Field \(\times\) Condition interaction in the context of a large Condition effect \((F(2/14)=33.52, p=.0001)\) and a significant Condition \(\times\) Order interaction \((F(2/14)=5.23, p=.02)\).

This experiment included data from both male and female subjects, as compared to Farah (1986) who studied only males. Numerous studies have examined sex differences in the cerebral lateralization of various verbal and nonverbal functions (for reviews see Bryden, 1979; McGlone, 1980; and Farah, 1982). Although some researchers have concluded that males are more lateralized in central function than females (McGlone, 1980), others find this conclusion premature (Bryden, 1979; Farah, 1982). To determine whether the current results were due to a difference in laterality between the sexes, the data from males and females were analyzed separately. The results of these separate analyses were similar to the results when all subjects were combined. There was no main effect of Visual Field or a Visual Field \(\times\) Condition interaction for either males or females, in the context of a significant Condition main effect in both cases \((p=.04)\) for males, \(p=.03\) for females.

During the initial experiment, in addition testing for handedness, each subject was asked if or she had any left-handed immediate family members. This was true for only three of the female subjects and for one of the male subjects. Reanalyzing the data without these subjects did not change the results.

The lack of a significant Visual Field \(\times\) Condition interaction in the previous analyses could result from different situations. Either no differential hemifield reaction time reductions result from using visual imagery or there are hemifield reaction time reductions using visual imagery, but some subjects a preferential left-visual-field whereas others demonstrate a preferential right-visual-field reduction. In order to determine these situations was present in our data's target reaction time data were averaged using a 3(Condition: baseline, similar image) \(\times\) 2(Visual Field: left, right) repeated measures MANOVA, with trials taken as independent observations.

Table 2 contains the reaction time data from all subjects. The lack of a significant Visual Field \(\times\) Condition interaction in the previous analyses could result from different situations. Either no differential hemifield reaction time reductions result from using visual imagery or there are hemifield reaction time reductions using visual imagery, but some subjects a preferential left-visual-field whereas others demonstrate a preferential right-visual-field reduction.

<table>
<thead>
<tr>
<th>Visual Field</th>
<th>Nontarget</th>
<th>Target</th>
<th>Nontarget</th>
<th>Target</th>
<th>Nontarget</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>543 (82)</td>
<td>509 (99)</td>
<td>570 (88)</td>
<td>536 (111)</td>
<td>572 (82)</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>525 (82)</td>
<td>513 (77)</td>
<td>569 (93)</td>
<td>554 (91)</td>
<td>575 (67)</td>
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</table>

### Table 1

**Initial experiment: Reaction time**

<table>
<thead>
<tr>
<th></th>
<th>Baseline Condition</th>
<th>Imagery Condition</th>
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<tbody>
<tr>
<td></td>
<td>Nontarget Target</td>
<td>Similar Target</td>
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<tr>
<td><strong>Visual Field</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Overall (N = 22)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Left</strong></td>
<td>534 (95) 513 (105)</td>
<td>528 (98) 475 (129)</td>
</tr>
<tr>
<td><strong>Right</strong></td>
<td>513 (88) 511 (104)</td>
<td>522 (102) 479 (136)</td>
</tr>
<tr>
<td><strong>Order 1 (n = 11)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Left</strong></td>
<td>524 (110) 518 (114)</td>
<td>486 (93) 415 (120)</td>
</tr>
<tr>
<td><strong>Right</strong></td>
<td>500 (96) 510 (129)</td>
<td>476 (91) 403 (174)</td>
</tr>
<tr>
<td><strong>Order 2 (n = 11)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Left</strong></td>
<td>543 (82) 509 (99)</td>
<td>570 (88) 536 (111)</td>
</tr>
<tr>
<td><strong>Right</strong></td>
<td>525 (82) 513 (77)</td>
<td>569 (93) 554 (91)</td>
</tr>
</tbody>
</table>
from using visual imagery or there are preferential hemifield reaction time reductions that result from using visual imagery, but some subjects demonstrate a preferential left-visual-field reduction whereas others demonstrate a preferential right-visual-field reduction. In order to determine which of these situations was present in our data, each subject's target reaction time data were analyzed separately using a 3(Condition: baseline, similar image, dissimilar image) × 2(Visual Field: left vs. right) repeated measures MANOVA, with the various trials taken as independent observations. None of the individual subject analyses resulted in significant Visual Field × Condition interactions. Only 4 subjects showed even a trend (p-value between .05 and .15) toward a preferential hemifield reaction time reduction with 2 of them demonstrating a trend toward a left-visual-field advantage with imagery, and the other two demonstrating a trend toward a right-visual-field advantage with imagery. Because order effects were inextricably confounded with the baseline target data, a similar analysis was performed comparing the target reaction times from the similar and dissimilar image conditions only. There were significant Condition main effects (p < .05) for 12 of the 22 subjects, all indicating faster reaction times to similar image targets compared to dissimilar image targets. Three other subjects showed a trend in the same direction (p < .12). A significant Condition × Visual Field interaction (p < .05) was present only in the data from 2 subjects, with both demonstrating a left-visual-field (right hemisphere) advantage with imagery.

Table 2 contains the reaction time data from the repeat experiment, on 20 of the 22 subjects, which were analyzed in exactly the same manner as in the initial experiment. The results of the analyses were very similar to those presented above. Once again, the statistically significant findings were a Condition × Order interaction (F(2/17) = 8.22, p = .003) and a main effect of Condition (F(2/17) = 11.34, p = .0007). There was no main effect of Order (F(1/18) = .01). The partitioning of the Condition effect into two 1-degree-of-freedom contrasts yielded different results from the first experiment in two ways. First, with Order included in the MANOVA model, the contrast between target reaction times in the baseline and similar image conditions yielded a larger effect (F(1/18) = 10.04, p = .005). Second, the interaction between Order and the contrast between reaction times to similar vs. dissimilar image targets was nonsignificant in the repeat experiment (F(1/18) = .75). Thus, the major difference in results between the first and repeat experiments is that the condition effects were somewhat larger in the repeat experiment whereas the order effects were somewhat smaller.

**Task Performance Accuracy and Eye Movements**

The error rates for the task and the number of trials lost to eye movements were analyzed in the same manner as were the median reaction times. Error rates ranged from 13% to 19%, and between 6% and 11% of trials were lost to eye movements over the different conditions. There were no significant main effects or interactions in either experiment for error rates or eye movements.

**P300 Latency**

Initial measures of P300 latency were derived from the averages, for each subject, of the evoked potentials recorded in response to each of the six
target conditions. P300 latency was defined as the latency of the maximum amplitude between 270 and 900 ms in the \( P_2 \) recording, provided that a similar peak with comparable latency was also present in the \( C_z \) waveform. These latency measures were analyzed using the same repeated measures MANOVA design as for the reaction times. The only significant finding was a main effect of Condition \( (F(2/19)=3.5295, \ p=.05) \). There were no main effects of either Order or Visual Field, and no interaction effects were observed. The Condition effect resulted from an earlier P300 latency for similar image targets compared to the baseline condition \( (F(1/20)=6.47, \ p=.02) \) and a trend for earlier P300 latency for similar image targets compared to dissimilar image targets \( (F(1/20)=3.58, \ p=.07) \).

The use of average evoked potential waveforms to measure P300 latency assumes that the endogenous P300 response does not vary across the single trials that comprise the average. However, there is evidence that even the exogenous potential evoked by a simple flash stimulus can exhibit considerable trial-to-trial heterogeneity (Möcks, Gasser, & Pham, 1984). The possibility was considered that P300 latency had varied across the trials and that differential Visual Field effects, if present, might have been obscured by the use of average waveforms. To determine whether trial-to-trial variability of P300 latency, for a given subject and condition, was an important factor, a recently developed statistical test of latency jitter was employed (Möcks, Kohler, Gasser, & Pham, 1988). The results of this test suggested that the prevalence of single-trial P300 latency variability was quite high. Of 132 tests of latency jitter for the interval from 270–900 ms poststimulus (22 subjects \( \times \) 6 conditions), 53 were significant at \( p<.05 \). Nineteen of the 22 subjects had a statistically significant degree of jitter in one or more conditions, and the presence of latency jitter was not related to either the visual field or the imagery status of the stimulus.

In the face of such extensive signal heterogeneity, the decision was made to measure P300 latencies directly from the single-trial data. The ability to accurately identify underlying components on single trials, even after appropriate filtering, requires that the signal-to-noise ratio of the data be high. Visual inspection of the waveforms suggested that this was the case, but to confirm this an estimate was computed of the signal-to-noise ratio on the single-trial data for each subject and condition (For equations to estimate signal-to-noise ratio (SNR), and comparative SNR estimates from other experimental paradigms, see Turetsky, Raz, & Fein, 1988.) The median SNR estimates across subjects for the six conditions, ranged from 0.64 to 0.91. In our experience, these values represent very high SNR estimates for evoked potential data. The true ratios are probably considerably higher, because the presence of extensive latency jitter produces a negative bias in the estimated SNR. To facilitate detection of the P300 peak, each single-trial evoked potential was first subjected to a low pass digital filter, using Blackman’s “lucky guess” window function (Blackman & Tukey, 1959), down 3dB at 32 Hz and down to zero at 11.25 Hz. The latency of the P300 component was defined as the first positive peak between 270 and 900 stimulus in the filtered P2 waveform. High signal-to-noise ratios in the data set little uncertainty in the identification of the component peak in each single trial. The median single-trial means was then the latency of P300 for each subject and condition. The P300 latency measures for the initial experiment from the average and the single-trial waveforms presented in Tables 3 and 4 respectively. Both the means and standard deviation of the standard deviation of the latency are larger for the average waveform than for the single trial averages; this is a reflection of the broadening of peaks that is introduced into the waveform by averaging together single trials with different latencies.

The median single-trial latencies were almost the same as the average evoked potential measurements of P300. The use of single-trial latency reveal any additional significant relation those relationships that were observed were even stronger in the single-trial measures only statistically significant effect was a main effect of Condition \( (F(2/19)=17.01, \ p<.0001) \). Partitioning of the Condition demonstrated an earlier P300 latency for similar image targets compared to the baseline condition \( (F(1/20)=32.23, \ p=.0001) \), and earlier P300 latency in the similar compared to dissimilar conditions \( (F(1/20)=30.06, \ p=.0001) \). There was an increase when the 4 subjects who had a consistent speeding of P300 late latency.

<table>
<thead>
<tr>
<th>Table 3</th>
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<tbody>
<tr>
<td>Initial experiment: P300 latency data, using average evoked potential measurement of P300</td>
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<table>
<thead>
<tr>
<th></th>
<th>Baseline Condition</th>
<th>Imagery Condition</th>
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</thead>
<tbody>
<tr>
<td>Visual Field</td>
<td>Nontarget</td>
<td>Target</td>
</tr>
<tr>
<td>Nontarget</td>
<td>Similar Image</td>
<td>Dissimilar Image</td>
</tr>
<tr>
<td>Overall (N = 22)</td>
<td></td>
<td></td>
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<tr>
<td>Left</td>
<td>550 (107)</td>
<td>530 (108)</td>
</tr>
<tr>
<td>Right</td>
<td>564 (123)</td>
<td>535 (105)</td>
</tr>
<tr>
<td>Order 1 (n = 11)</td>
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<td></td>
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<tr>
<td>Left</td>
<td>521 (121)</td>
<td>515 (114)</td>
</tr>
<tr>
<td>Right</td>
<td>549 (105)</td>
<td>524 (109)</td>
</tr>
<tr>
<td>Order 2 (n = 11)</td>
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<td></td>
</tr>
<tr>
<td>Left</td>
<td>579 (88)</td>
<td>544 (105)</td>
</tr>
<tr>
<td>Right</td>
<td>578 (142)</td>
<td>545 (104)</td>
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</table>
Laterality of Mental Image Generation

Table 4

<table>
<thead>
<tr>
<th></th>
<th>Baseline Condition</th>
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<tbody>
<tr>
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<td>Nontarget</td>
<td>Target</td>
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<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Visual Field</td>
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<td></td>
</tr>
<tr>
<td>Left</td>
<td>457 (38)</td>
<td>468 (37)</td>
</tr>
<tr>
<td>Right</td>
<td>452 (42)</td>
<td>457 (46)</td>
</tr>
<tr>
<td>Overall (N=22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>460 (42)</td>
<td>461 (28)</td>
</tr>
<tr>
<td>Right</td>
<td>455 (47)</td>
<td>454 (42)</td>
</tr>
<tr>
<td>Order 1 (n=11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>455 (35)</td>
<td>476 (45)</td>
</tr>
<tr>
<td>Right</td>
<td>448 (37)</td>
<td>459 (52)</td>
</tr>
<tr>
<td>Order 2 (n=11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>455 (31)</td>
<td>471 (45)</td>
</tr>
<tr>
<td>Right</td>
<td>448 (35)</td>
<td>459 (52)</td>
</tr>
</tbody>
</table>

Reaction Time Data with P300 Latency as a Covariate

The reaction time data were examined after removing variation accounted for by differences in P300 latency. Using BMDP2V, P300 latency was treated as a covariate for each median reaction time observation. Because this program does not perform a multivariate repeated-measures analysis, the p-values reported below are the Greenhouse-Geisser adjusted p-values. After controlling for P300 latency, there was still a statistically significant (although smaller) Condition effect for target reaction times in the initial experiment (F(2/39)=4.21, p=.03), and a trend for the effect in the repeat experiment (F(2/35)=2.54, p=.10). The Order × Con-
diation interactions were somewhat larger after adjusting for the P300 latency covariate ($F(2/39) = 10.25, p = .001$; and $F(2/35) = 7.72, p = .002$; in the initial and repeat experiments, respectively).

**Test-Retest Reliability**

Pairwise Pearson’s correlation coefficients were computed between the percent reaction time decrease, P300 latency reduction, and order effects (for the reaction time data) from the initial experiment and the comparable measures from the repeat experiment, to determine the reliability of these effects across experimental replications that were at least one month apart. The correlations were .60, .59, and .58 for the percent reaction time decrease, P300 latency reduction, and order effect respectively (all $p<.01$).

**Discussion**

These results failed to replicate Farah’s (1986) finding of a left-hemispheric locus for the generation of mental images. For that matter, they also failed to support a right-hemispheric locus for mental image generation. There were no significant visual field × condition interactions of any kind in any of the analyses of error rates, reaction times, or P300 latencies.

These findings are consistent with the hypothesis that both hemispheres are capable of generating and using simple mental images. This hypothesis has also received support from several other studies recently reviewed by Kosslyn (1988). These studies have indicated that the formation of mental image involves two types of processes, those that activate stored memories of the appearances of parts of forms, and those that arrange parts into the proper configuration. The results provided evidence that both hemispheres have the ability to generate mental images of the component parts of forms, but they apparently differ in the preferred way of arranging them. The left hemisphere was superior when categorical relations could be used to arrange the parts, whereas the right hemisphere at combining parts using coordinate relations. In the present experiment, the images were fully formed prior to the presentation, and there would have been no process over the other. Both have been effectively utilized in forming the images, therefore making the effect of same in both visual fields. This was result by the lack of any condition interactions.

This failure to demonstrate visual field for the reaction time decrease association did not result from an overall in the paradigm to the effects of imagery on consistent main effects of imagery on action time and P300 latency measured. It is conceivable that the absence of a visual field resulted from inadequate lateralization or a failure to control for interference. However, the combination of
phrases have the ability to generate mental images. For that matter, they also support a right-hemispheric locus for mental image generation. There were no significant visuo-spatial condition interactions of any kind in analyses of error rates, reaction times, or quartile range, and extremes of the frequency distribution. Similar image, dissimilar image, and baseline target conditions are displayed separately for each subject. The earlier P300 distributions were fully formed prior to the stimulus presentation. Responses to similar image targets for one process over the other. Both could have been effectively utilized in forming the mental images, therefore making the effect of imagery the same in both visual fields. This was reflected in the results by the lack of any condition × visual field interactions.

This failure to demonstrate visual field effects for the reaction time decrease associated with imagery did not result from an overall insensitivity of the paradigm to the effects of imagery. There were consistent main effects of imagery on both the reaction time and P300 latency measures. It is conceivable that the absence of a visual field effect resulted from inadequate lateralization of stimulus presentation or a failure to control for gaze preference. However, the combination of visual monitoring of gaze fixation and the automatic rejection of trials with EOG artifact make this an unlikely explanation.

The reaction times in this experiment were from 167 to 339 ms faster, depending on condition, than those in Farah's experiment. This is probably the result of stimuli that were easier to discriminate (i.e., more pixels per stimulus), longer stimulus exposure (67 ms vs. 50 ms), and easier response requirements (lifting a finger vs. pressing a response button). Although it is possible that these paradigm differences might have reduced the differential effect of imagery in the two visual fields, it seems doubtful that they could have completely eliminated this effect while leaving the general effects of imagery on reaction time intact, as evidenced in our experimental data.

This experiment included data from male and female subjects. In addition, three of the female subjects and one male subject had a familial history of left-handedness. Farah (1986) used only right-handed subjects. Top: Left visual hemifield stimulus presentation. Responses to similar image targets for each subject. The similar image target condition interactions of any kind in the paradigm to the effects of imagery. There were no significant visuo-spatial condition interactions of any kind in analyses of error rates, reaction times, or quartile range, and extremes of the frequency distribution. Similar image, dissimilar image, and baseline target conditions are displayed separately for each subject. The earlier P300 distributions were fully formed prior to the stimulus presentation. Responses to similar image targets for one process over the other. Both could have been effectively utilized in forming the mental images, therefore making the effect of imagery the same in both visual fields. This was reflected in the results by the lack of any condition × visual field interactions.

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Figure 2. Box plot representations (SAS Institute Inc., 1985) of the single trial P300 latency distributions for 3 subjects whose average evoked potential waveforms are presented in Figure 1. Top: Left visual hemifield stimulus presentation. Bottom: Right visual hemifield stimulus presentation. Each box plot denotes the mean, median, interquartile range, and extremes of the frequency distribution. Similar image, dissimilar image, and baseline target conditions are displayed separately for each subject. The earlier P300 of the similar image, compared to the baseline and dissimilar image conditions, is consistently illustrated for stimuli presented to either visual field.
handed males, with no left-handed relatives. As previously mentioned, it is possible that the choice of subjects affected the sensitivity of the experiment. However, the results of the various analyses argue against this. Males and females did not differ in their experimental results. Nor did the results change when the four subjects with a familial history of left-handedness were dropped from the analysis. Furthermore, the analyses of reaction times for individual subjects yielded significant condition effects, but did not yield a single significant condition × visual field interaction when the analysis included all of the target conditions, and only two such interactions when the analysis included only the imagery target conditions. These results suggest that neither the subject’s sex, nor a familial history of left-handedness were mediating factors in this experiment. However, it was not possible to analyze the data to evaluate all the above factors in combination. Consequently, although Farah’s conclusions may not generalize across the population at large, they may obtain for a selected subset.

The use of mental imagery decreased P300 latency for stimulus presentation in either hemifield when the image and stimulus matched. This agrees with previous reports that mental images can be used as templates to facilitate stimulus discrimination (Bisiach & Luzzatti, 1978; Shepard & Cooper, 1982). However, mental imagery appears capable of speeding response processing in addition to stimulus evaluation, as evidenced by the significant condition effect remaining after variation accounted for by differences in P300 latency was removed. The lack of any significant interactions with order in the analysis of the P300 data indicates that order of condition presentation primarily affects the response processing portion of the reaction time and in fact, the order × condition interactions were larger when the reaction time data were analyzed with P300 latency as a covariate.

As is apparent in Figure 1, the averaged evoked potentials indicate an early negative shift. This could reflect the subject’s anticipation of a stimulus presentation developed after the initiation of each trial with the foot pedal. The figures also illustrate the very large P300 amplitudes produced by this experimental paradigm.

The results from the initial and repeat experiments were essentially the same, the basic differences being in the size of the condition and order effects. As subjects became more familiar with the task, the ability of imagery to speed reaction times became greater and the order of condition presentation had less influence on the results.

In summary, this experiment provided no support for a preferential locus of mental image generation in either the left or the right hemisphere. Rather, each hemisphere appears to be capable of generating and using simple mental images to speed both stimulus evaluation and response processing. Future research could determine if these results would also apply with more complex images and more difficult image manipulations.

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