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Hemispheric differences are found in the identification, but not the detection, of low versus high spatial frequencies

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The processing of sine-wave gratings presented to the left and right visual fields was examined in four experiments. Subjects were required either to detect the presence of a grating (Experiments 1 and 2) or to identify the spatial frequency of a grating (Experiments 3 and 4). Orthogonally to this, the stimuli were presented either at threshold levels of contrast (Experiments 1 and 3) or at suprathreshold levels (Experiments 2 and 4). Visual field and spatial frequency interacted when the task required identification of spatial frequency, but not when it required only stimulus detection. Regardless of contrast level (threshold, suprathreshold), high-frequency gratings were identified more readily in the right visual field (left hemisphere), whereas low-frequency gratings showed no visual field difference (Experiment 3) or were identified more readily in the left visual field (right hemisphere) (Experiment 4). Thus, hemispheric asymmetries in the processing of spatial frequencies depend on the task. These results support Sergent's (1982) spatial frequency hypothesis, but only when the computational demands of the task exceed those required for the simple detection of the stimuli.

Perceptual characteristics of input, as well as cognitive characteristics of task, have been shown (by, e.g., Sergent & Hellige, 1986) to influence obtained patterns of cerebral asymmetry. Sergent (1982, 1983) proposed that the right visual field/left hemisphere (RVF/LH) is specialized for the perceptual processing of higher spatial frequencies, and that the left visual field/right hemisphere (LVF/RH) is specialized for the processing of lower spatial frequencies. Two general strategies, one involving complex stimuli and the other, simple stimuli, have been employed in testing this hypothesis, and each strategy will be discussed below in turn.

Strategy 1: Complex Stimuli

First, some researchers have used complex stimuli (e.g., alphanumeric characters, faces) and have varied input characteristics (e.g., size, eccentricity, luminance, exposure duration) in order to vary the proportion of high and low frequencies in the input. When Christman (1989) reviewed such studies, he found moderate support for the spatial frequency hypothesis. However, the manipulations used in these studies have only crude and/or indirect effects on the spatial frequency content of the input, and thus they cannot be considered simple or straightforward manipulations of spatial frequency as opposed to other input variables (e.g., stimulus perceptibility; see Michimata & Hellige, 1987).

In only four studies have quantitative forms of spatial filtering been employed to directly test the spatial frequency hypothesis. Sergent (1985) presented clear versus low-pass blurred faces and found, as predicted by the hypothesis, that low-pass blurring produced greater relative LH impairment. In a similar experiment, however, Sergent (1987) obtained an LH advantage with broad-pass faces and no hemispheric differences with low-pass faces. Christman (1990) used dioptric blur to filter out higher frequencies in a temporal integration task that required the identification of digits. He found that low-pass blur produced greater LH impairment. Finally, Peterzell, Harvey, and Hardyck (1989) used band-pass filtering in a letter-classification task and found no interaction between spatial frequency and hemispheric advantage.

These results suggest that factors such as exposure duration, task requirements, and stimulus perceptibility play a role above and beyond any effects of spatial frequency. In particular, the spatial frequency hypothesis stresses that hemispheric asymmetries depend on the interaction of the range of spatial frequencies *available* in the input with the range of frequencies *required* by processing demands of the task.

In the studies cited above, there was explicit control and knowledge of the spatial frequencies available in the input, but not of those required by the task. Sergent (1987) pointed out the importance of "our ignorance about which spatial frequencies convey the relevant information for optimal performance in a particular task" (p. 424). Thus,

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the inconsistent results obtained by Peterzell et al. (1989) and by Sergent (1987) may have arisen due to task, as well as input, characteristics.

Strategy 2: Simple Stimuli

An alternative strategy in testing the spatial frequency hypothesis is to present stimuli whose spatial frequency spectra are simple and known (e.g., sine-wave gratings). This not only permits explicit control over the frequencies available in the input, but also allows for explicit knowledge of the spatial frequencies required for processing in the task at hand. The single frequency available in the input is, by definition, the only frequency that can be required for successful processing. Thus, paradigms employing single-component sine-wave grating stimuli provide a useful method of unambiguously examining the effects of input characteristics and their interaction with task requirements.

To date, studies done with grating stimuli have involved the use of either discrimination or detection tasks to test for hemispheric differences. With the discrimination task, the conclusions from relatively few studies have been equivocal. Fiorentini and Berardi (1984) tested at only one spatial frequency (1 c/deg) and found some suggestion of a small RH advantage, as predicted by the spatial frequency hypothesis. It is obvious that their results are limited. Szelag, Budohoska, and Koltuska (1987), who used a wide range of base spatial frequencies, found no evidence for hemispheric differences in the time needed to discriminate whether two successively presented gratings were the same or different. However, the changes in mean luminance that accompanied presentation of the gratings might have differentially masked high and low spatial frequencies (Badcock & Sevdalis, 1987). Thus, the evaluation of hemispheric differences is confounded by potential differences in hemispheric susceptibility to masking. Similarly, Boles and Morelli (1988) failed to control for changes in mean luminance. When mean luminance is controlled, hemispheric effects are found, with discrimination of low spatial frequencies being faster for LVF/RH presentations and discrimination of high spatial frequencies being faster for RVF/LH presentations (Kitterle, 1990).

With the detection task, a number of studies have failed to find hemispheric differences in contrast sensitivity (Blake & Mills, 1979; Fiorentini & Berardi, 1984; Kitterle & Kaye, 1985; Peterzell et al., 1989; Rao, Rourke, & Whitman, 1981). Earlier studies that showed hemispheric differences in contrast sensitivity (Beaton & Blakemore, 1981; Rovamo & Virsu, 1979) have not been replicated, and it is possible that these earlier findings were the result of individual differences in nasal and temporal hemiretinal sensitivity, since only monocular viewing was used.

Why are hemispheric differences not found in threshold detection of spatial frequency? The detection of a grating is a relatively simple task. Perhaps hemispheric asymmetries arise only when there is a limited capacity for handling information or for allocating attention (Rose, 1983). In addition, the detection of a grating may occur relatively early in processing. In the initial formulation of the spatial frequency hypothesis, Sergent (1982) wrote that "hemispheric differences as a function of spatial frequency must result from processing taking place beyond the sensory level" (pp. 265-266).

But what constitutes processing "beyond the sensory level"? There are at least three possibilities. One possibility is to assume that simple detection occurs at a sensory level; therefore, hemispheric differences would arise only when some higher level processing of the input is required (e.g., discrimination, identification). Differences in hemispheric processing tend to occur in psychophysical tasks that require relatively extensive computation by the visual system (Christman, 1988; Cohen, 1982; Greenwood, Rotkin, Wilson, & Gazzaniga, 1980; Kitterle, 1986; Rose, 1983). Thus, if hemispheric differences depend on computational processes that monitor and compare the output of different spatial frequency channels, one might expect to find laterality effects in spatial frequency discrimination and identification tasks. Discrimination requires an intermediate level of information processing in between the levels of information necessary for detection and identification judgments (see, e.g., Uttal, 1988). Thus, identification tasks should require more computation and consequently be more likely to result in hemispheric asymmetries. To date, the identification of sine-wave gratings in the LH versus the RH has not been examined in any studies. One of our primary purposes in the present paper, therefore, is to present experiments carried out to examine the ability of the LH versus the RH in order to identify threshold and suprathreshold gratings of low versus high spatial frequency.

A second possibility is to assume that threshold levels of stimulus contrast constitute a sensory level; hemispheric differences would therefore arise only when suprathreshold stimuli were used. A third possibility is the conjunction of the previous two; that is, hemispheric differences arise only when discrimination or identification judgments are performed on suprathreshold-level stimuli. This suggests a 2×2 matrix consisting of the four combinations of two levels of task (i.e., detection and identification) and two levels of input (i.e., threshold and suprathreshold), as depicted in Figure 1. With this in mind, we present here five independent experiments: In Experiments 1 and 2, we examined detection of gratings at threshold and suprathreshold levels, respectively, whereas in Experiments 3, 4, and 5, we examined sine-wave grating identification at threshold and suprathreshold levels. In this way, all possible combinations of task level and input contrast level were investigated.

If task and computational requirements are critical, only Experiments 3, 4, and 5 (involving identification tasks) would be expected to yield hemisphere × spatial frequency interactions. If input contrast level is critical, then Experiments 2, 4, and 5 (involving suprathreshold stimuli) would be expected to yield hemispheric effects. Lastly,

CONTRAST LEVEL	TASK VARIABLES: DETECTION	TASK VARIABLES: IDENTIFICATION
THRESHOLD	EXP. 1	EXP. 3
SUPRATHRESHOLD	EXP. 2	EXP. 4 EXP. 4A

Figure 1. A summary of all the experiments in this study, represented as a 2×2 table that shows all possible combinations of task level (detection vs. identification) × input contrast level (threshold vs. suprathreshold).

if higher level task requirements performed on suprathreshold stimuli are critical, then only Experiments 4 and 5 (suprathreshold identification) would be expected to yield hemispheric effects.

GENERAL METHOD

Features that are common to all five experiments are described in the next section, followed by procedures and methods unique to each experiment.

The stimuli (vertically oriented sinusoidal gratings) were generated by a Picasso CRT Spatio-Temporal Image Synthesizer (Innisfree) under computer control and displayed on two Tektronix 608 monitors (P-31 phosphor, which decays to 1% intensity at .25 msec after display offset). Holes in the large black matte surround (30° high × 36° wide at a viewing distance of 42 in.) placed directly in front of the monitors masked their screens down to two 6.8° circular displays. The inner edge of each screen was 3° from the small red fixation point placed between the two CRTs. Signals to the *x*- and *y*-axes of both monitors produced uniformly lit screens (mean luminance of 10.3 cd/m^2). Signals to the *z*-axis of the monitors produced the various spatial frequencies. The amplitude of these signals controlled the contrast, *C*, defined as

$$(L_{max} - L_{min}) / (L_{max} + L_{min}),$$

where L_{max} is the maximum luminance and L_{min} is the minimum luminance. Because contrast was modulated about the mean luminance of the screens, the level of light adaptation did not change when the gratings were abruptly turned on and off. Both contrast and mean luminances were measured with a Tektronix J16 photometer/radiometer. Care was taken throughout the study to ensure that the monitors remained matched in mean luminance and that the contrast calibrations did not drift.

At the beginning of the session, subjects were light-adapted for 2 min to the mean luminance of the display while the instructions were read. The instructions stressed the importance of looking at the red fixation light as soon as the warning tone was sounded and of maintaining fixation until after the response key was depressed. The warning tone preceded the gratings by a variable foreperiod (500-1,100 msec). The subjects viewed the displays binocularly through a viewing hood in a darkened room. The hood and a chinrest provided a means of stabilizing the subject's head during the session.

All subjects were naive about the purpose of the study, all reported that they had normal visual acuity, and all were right-handed males with no immediate family history of sinistrality. We assessed their handedness with a brief handedness questionnaire.

EXPERIMENT 1

Threshold Detection Under Uncertainty

Five previous studies (Blake & Mills, 1979; Fiorentini & Berardi, 1984; Kitterle & Kaye, 1985; Peterzell et al., 1989; Rao et al., 1981) did not yield hemispheric differences in spatial frequency processing in detection tasks at sensory threshold. However, these studies share some methodological limitations, as, for example, in the number and nature of subjects. Laterality studies typically require large numbers of subjects, because cerebral lateralization is an inherently noisy phenomenon with large intersubject variability. In none of the aforementioned studies, however, were more than 4 subjects used, and thus none is likely to have had sufficient power for the detection of hemispheric differences. In our Experiment 1, 10 subjects were used. In all of the aforementioned studies, only accuracy (percent detection) was examined. In the present experiments, both reaction time (RT) and accuracy were measured in order to obtain a broader picture of the nature of hemispheric processing. Conceivably, hemispheric differences in the ability to detect spatial frequency may appear only in terms of processing time, not processing accuracy.

Uncertainty affects threshold detection. The contrast threshold increases when subjects are uncertain about which spatial frequency will be presented and/or which spatial position it will be presented at (Davis & Graham, 1981; Davis, Kramer, & Graham, 1983). Subjects need to monitor more visual channels under conditions of uncertainty; because these channels are noisy and give rise to false alarms, performance deteriorates relative to conditions in which all resources can be devoted to the monitoring of a single channel.

All of the aforementioned five studies were run under conditions of maximum certainty; on any given trial, the subject knew exactly which frequency and which spatial position (i.e., visual field) was going to be employed. In the present Experiment 1, however, the subjects did not know from trial to trial which of five frequencies or which of two spatial positions (LVF vs. RVF) would occur. If there are hemispheric differences in the noisiness of spatial frequency channels, then conditions of uncertainty in Experiment 1 should be better suited at uncovering potential hemispheric differences in threshold detection of varying spatial frequencies.

Method

Subjects. Ten right-handed males received either course credit or $10 per hour for their participation.

Stimuli. The exposure duration for gratings was held constant at 150 msec. The stimulus set consisted of five spatial frequencies (0.75, 1.5, 3.0, 6.0, and 12.0 c/deg), each with four levels of contrast that were selected, on the basis of pilot data, to span a range that included sub- and slightly suprathreshold levels. The stimulus set also contained a set of zero contrast gratings that served as catch trials. An experimental block consisted of 102 trials: 80 stimulus trials (resulting from the factorial combination of 5 spatial frequencies × 4 levels of contrast × 2 visual fields × 2 foreperiod durations) and 22 catch trials (zero contrast gratings) on which no stimulus was presented.

Procedure. The method of constant stimuli was employed, so that the 102 trials were presented in a random order.

Each trial began with a warning tone, which alerted the subject that a stimulus might or might not occur after a foreperiod of 650 or 800 msec. To indicate whether or not they had detected the presence of a grating, half of the subjects then responded "present" by pressing a key with the left index finger and "absent" by pressing a key with the right index finger; the other half responded with the reverse order.

Each subject participated in a total of 14 experimental blocks of 102 trials each. The subjects were run in two separate sessions of 7 blocks each. A brief rest period followed each block, and an extended break was given after the 4th block of each session.

Results and Discussion

Regression analyses indicated the contrast (and associated median RT) necessary to achieve 75% correct detection for each spatial frequency in the LVF versus the RVF. This served to normalize the data and to help smooth out individual differences in overall levels of performance. Figure 2A shows the derived contrast sensitivity functions for the LVF and RVF. Figure 2B shows the associated RTs. Analyses of variance (ANOVAs) were performed on the contrasts and RTs associated with 75% correct detection, with spatial frequency and visual field as within-subject variables, and hand of response as a between-subject variable.

Contrast threshold data. There were no significant main effects of hand of response $[F(1,8) = 1.2, p > .20]$ or visual field $[F(1,8) = 1.94, p > .20]$. There was a significant effect of spatial frequency $[F(4,32) = 94.56, p < .00001]$, with higher frequencies requiring greater contrast for detection. There were no significant interactions between hand of response and spatial frequency $[F(4,32) < 1]$, hand of response and visual field $[F(1,8) = 1.95, p > .20]$, or spatial frequency and visual field $[F(4,32) = 1.73, p > .16]$. Finally, the three-way interaction between hand of response, spatial frequency, and visual field was also nonsignificant $[F(4,32) = 1.94, p > .12]$. Thus, there were no hemispheric asymmetries in contrast sensitivity as a function of spatial frequency, even under conditions of maximal stimulus uncertainty.

Reaction time data. There was no main effect of hand of response $[F(1,8) = 1.22, p > .30]$. There was a significant effect of spatial frequency $[F(4,32) = 6.23, p < .002]$, with higher frequencies yielding longer RTs. The main effect of visual field was nonsignificant $[F(1,8) = 4.37, p < .07]$, although there is some suggestion that there are slightly faster RTs with RVF stimuli. Visual field did not interact with spatial frequency $[F(4,32) < 1]$, suggesting that (in accord with the contrast threshold data) there were no hemispheric differences as a function of spatial frequency.

There was also no interaction between visual field and hand of response $[F(1,8) = 1.17, p > .31]$. The interaction between hand of response and spatial frequency was nonsignificant $[F(4,32) = 2.18, p < .10]$.

EXPERIMENT 2

Grating Detection at Suprathreshold Levels

In Experiment 1, as in previous experiments that also required the threshold detection of sine-wave gratings, no hemispheric asymmetries were found. As discussed earlier, Experiment 2 was designed to test whether or not an interaction of spatial frequency and visual field would

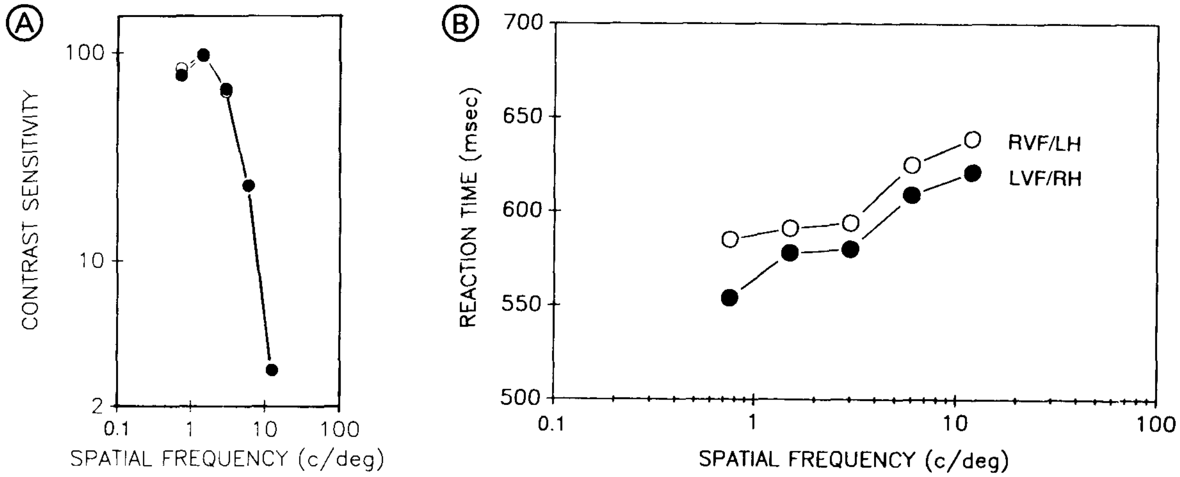

Figure 2. (A) Contrast sensitivity as a function of spatial frequency for left visual field (LVF, filled circles) and right visual field (RVF, unfilled circles) presentations under spatial position and spatial frequency uncertainty. (B) Reaction time to detect threshold-level gratings as a function of contrast under spatial position and spatial frequency uncertainty. Filled circles plot LVF presentations and unfilled circles plot the data for RVF presentations.

emerge in the detection task at suprathreshold levels of stimulus contrast. Because stimuli were shown at suprathreshold contrasts, no detection errors occurred, and only RT data will be reported.

Method

Subjects. Twelve right-handed males participated for course credit.

Stimuli. Spatial frequencies of 1, 3, and 10 c/deg were used in this experiment. Contrast was also varied in this experiment (.1, .2, and .4). There were two exposure durations (50 and 200 msec).

Procedure. The subjects were required to depress a response key as soon as they saw a grating. The grating was presented to either the right or the left of fixation at a variable time after a warning tone. There was a 1-sec intertrial interval.

The design of the experiment involved two viewing conditions (LVF or RVF presentation), three spatial frequencies (1, 3, and 10 c/deg), three contrasts (.1, .2, and .4), and two exposure durations (50 and 200 msec) as within-subject variables. There were 20 replications of each condition and two rest periods within the experimental session. After the second rest period, the subject was instructed to respond with the opposite hand. Each observer had a series of practice trials. The analysis of this experiment was based on the mean of the median RTs of each condition.

Results

The results are shown in Figures 3A, 3B, and 3C, where RT is plotted as a function of spatial frequency for contrast levels of .1, .2, and .4, respectively. The left panel of each figure shows the results for a 50-msec exposure, and the right panel, the 100-msec exposure duration. In all figures, RTs are averaged over hand since this variable did not significantly interact with spatial frequency, duration, visual field, or contrast, or with any combination of these variables. A four-factor repeated measures ANOVA was conducted on these data.

There were significant main effects of spatial frequency [$F(2,22) = 21.33$, $p < .0001$], contrast [$F(2,22) = 132.52$, $p < .0001$], duration [$F(1,11) = 9.36$, $p < .05$], and visual field [$F(1,11) = 9.36$, $p < .01$]. Specifically, RT increased with spatial frequency, decreased with contrast and duration, and was shorter for LVF than for RVF presentations. In addition, there were significant first-order interactions of spatial frequency and contrast [$F(4,44) = 8.26$, $p < .0001$] and contrast and duration [$F(2,22) = 8.19$, $p < .002$]. However, despite an increased number of subjects and additional procedural controls not found in earlier studies, there were no significant spatial frequency × visual field [$F(2,22) = .95$, $p > .4$], spatial frequency × visual field × contrast [$F(4,44) = .93$, $p > .45$], spatial frequency × visual field × duration [$F(2,22) = .62$, $p > .53$], or spatial frequency × visual field × contrast × duration [$F(4,44) = .28$, $p > .82$] interactions. Thus, there were no hemispheric differences in suprathreshold detection of spatial frequency. These results reinforce the finding in Experiment 1 and previous studies of hemispheric symmetry in the *detection* of gratings.

EXPERIMENT 3

Threshold Identification

As mentioned earlier, visual field × spatial frequency interactions might be found in psychophysical tasks only when some higher level of processing of the input or more extensive computation by the visual system is required. For example, for *identification* of the spatial frequency presented, the output of the different spatial frequency channels must be both monitored and compared. For *detection*, on the other hand, it is not necessary to know which channel responded, only that there was activity in some channel. Threshold detection and identification may also be based on different decision processes (Thomas, 1985; Thomas, Gille, & Barker, 1982). The results of Experiments 1 and 2 indicate that both hemispheres operate on equivalent bases of sensory information and apply the same detection rules. However, the two hemispheres differ in response biases in other situations (see, e.g., Chiarello, Pollock, & Gage, 1988; Peterzell et al., 1989) and may differ in the computational processes or decision rules that lead to the identification of a stimulus as being of high versus low frequency. Experiment 3, therefore, was designed to determine whether hemispheric asymmetries are present in grating identification at threshold.

Method

Subjects. Eight right-handed males received either course credit or $10 per hour for their participation.

Stimuli. Two stimulus sets were used: a low-frequency set (0.75- and 1.5-c/deg vertical sine-wave gratings) and a high-frequency set (6.0- and 12.0-c/deg gratings). Each grating was paired with five contrast levels, chosen to span a range that included sub- and slightly suprathreshold levels and to yield equivalent detection performance (as determined by detection performance in Experiment 1) for each spatial frequency. This enabled us to examine, in Experiment 3, the ability of the LH versus the RH to *identify* different spatial frequencies that were equally *detectable*.

Procedure. An experimental block used a single stimulus set and consisted of 105 trials: 100 stimulus trials (resulting from the factorial combination of 2 spatial frequencies × 5 levels of contrast × 2 visual fields × 5 foreperiod intervals) and 5 catch trials on which no grating was presented. The method of constant stimuli was employed, so that the trials were presented in random order.

Each trial began with a warning tone, alerting the subject that a stimulus would be presented for 150 msec after a foreperiod of 600, 650, 700, 750, or 800 msec. The subjects were told to press one key if the stimulus with wide bars (i.e., 0.75-c/deg grating in the low-frequency set; 6.0 c/deg in the high-frequency set) had been presented, and to press the other key if the stimulus with narrow bars (i.e., 1.5 c/deg in the low-frequency set; 12 c/deg in the high-frequency set) had been presented. Half of the subjects responded "wide" with the left hand and "narrow" with the right; this arrangement was reversed for the other half.

The subjects were run in two separate sessions of eight blocks each, one session for each stimulus set. Half of the subjects received the low-frequency condition first, and the other half the high-frequency condition first. The subjects rested briefly at the midpoint of each session.

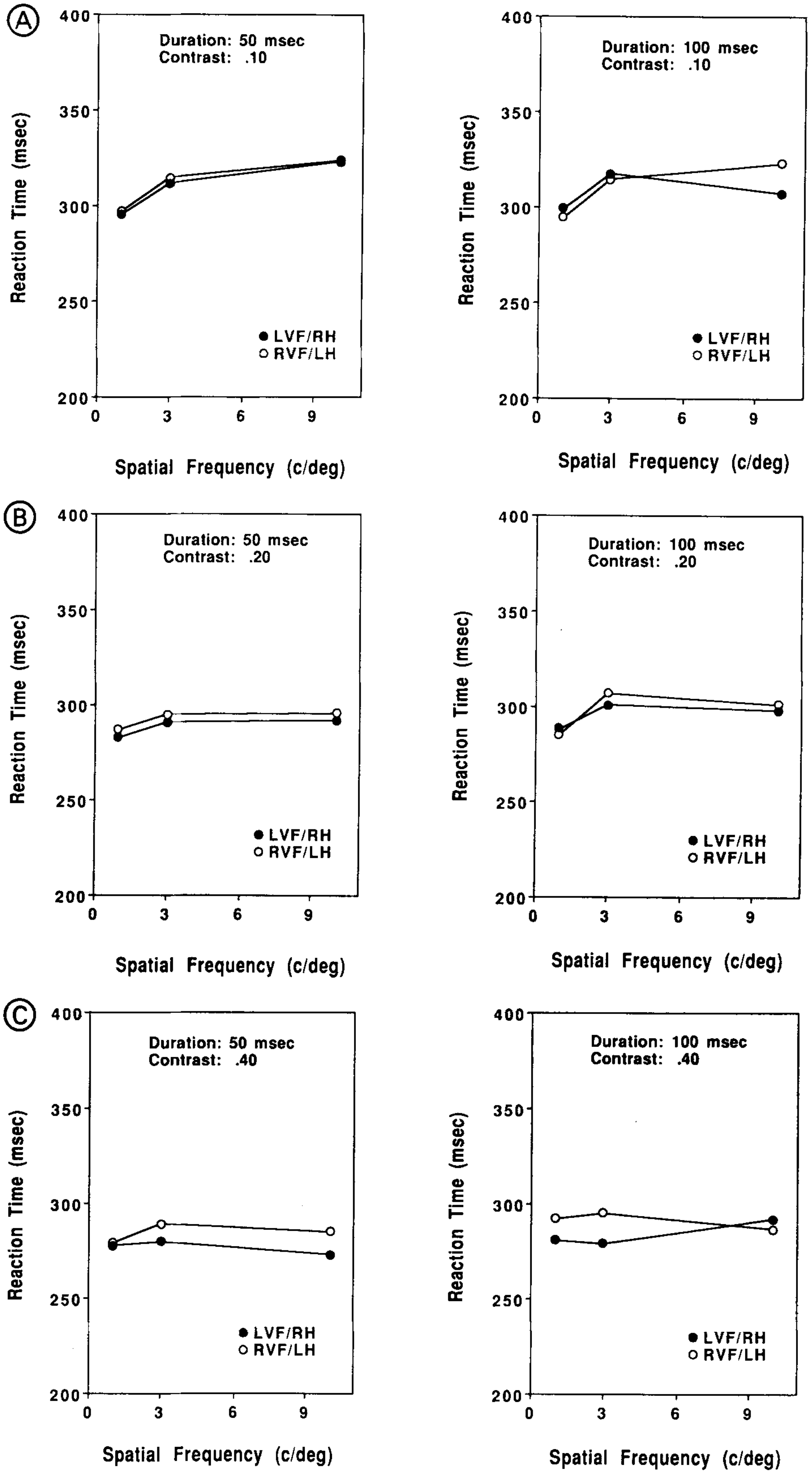

Figure 3. Reaction time to detect a suprathreshold-level grating as a function of contrast (A, .10; B, .20; C, .40) and exposure duration (50 msec, left panels, and 100 msec, right panels). Filled circles plot left visual field (LVF) presentations and unfilled circles plot the data for right visual field (RVF) presentations.

Results and Discussion

Contrast threshold data. The percent correct identifications as a function of visual field (LVF, RVF) and contrast level are shown in Figure 4A for the low-frequency condition and in Figure 4B for the high-frequency condition.

In this analysis, spatial frequency, visual field, and contrast level were within-subject variables. Performance improved as contrast increased [$F(4,24) = 50.73$, $p < .00001$], but no other main effect was significant. Although the predicted interaction between spatial frequency and visual field did not appear ($F < 1$), there was a significant three-way interaction between spatial frequency, visual field, and contrast level [$F(4,24) = 3.16$, $p < .04$]. Spatial frequency and visual field did not interact at Contrast Levels 1 ($F < 1$), 2 ($F < 1$), or 3 [$F(1,7) = 2.36, p > .16$], but did interact marginally at Contrast Level 4 [$F(1,7) = 4.25, p < .08$] and significantly at Contrast Level 5 [$F(1,7) = 5.48, p < .05$]. At Contrast Levels 4 and 5, there were no visual field differences in the low-frequency condition (Figure 4A) and a RVF advantage in the high-frequency condition (Figure 4B).

Reaction time data. Mean RTs are plotted in Figure 4C for the low-frequency condition and in Figure 4D for the high-frequency condition.

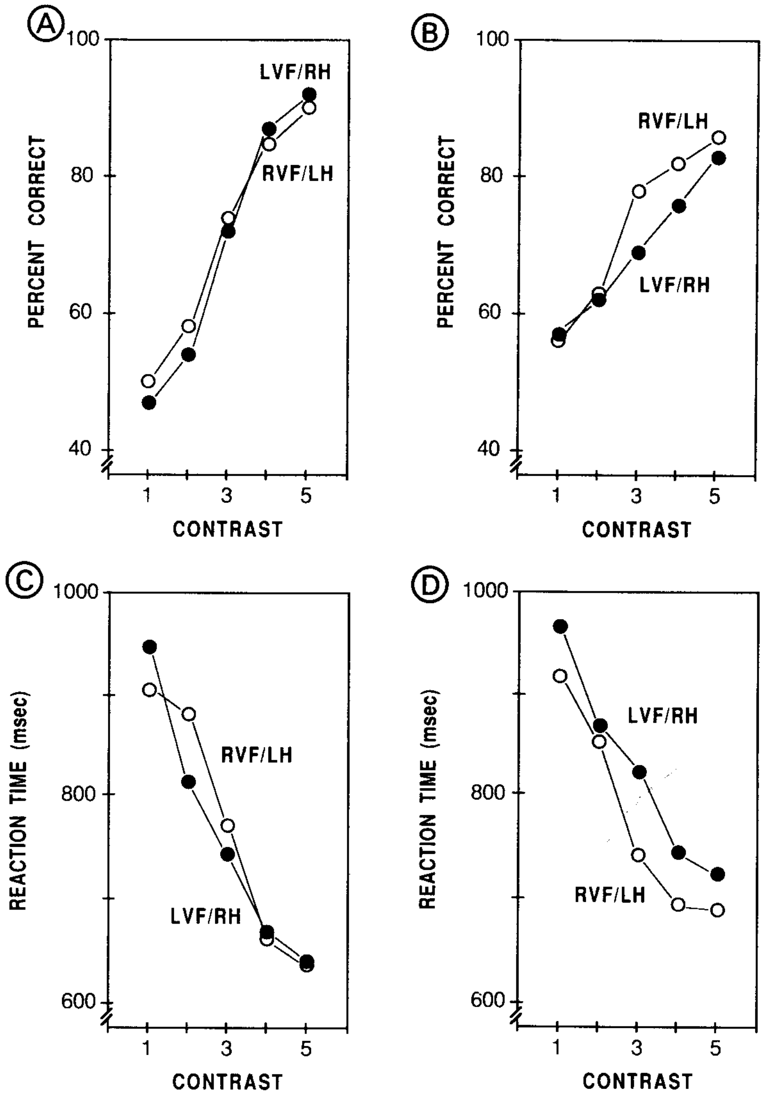

Figure 4. As a function of contrast (arbitrary units) for left visual field/right hemisphere (LVF/RH, filled circles) and right visual field/left hemisphere (RVF/LH, unfilled circles) presentations: (A) Frequency of seeing as a function of contrast (arbitrary units) for the identification of low-spatial-frequency gratings (.75 and 1.5 c/deg); (B) frequency of seeing as a function of contrast for the identification of high-spatial-frequency gratings (6 and 12 c/deg); (C) reaction times to identify low-spatial-frequency gratings (.75 and 1.5 c/deg); and (D) reaction times to identify high-spatial-frequency gratings (6 and 12 c/deg).

Mean RT decreased with contrast [$F(4,24) = 12.90$, $p < .00001$], but no other main effect was significant. To test for the hypothesized directional interaction between spatial frequency and visual field, we first obtained the difference scores between RTs for LVF and RVF presentations with low-spatial-frequency stimulus set and similar difference scores for high-spatial-frequency stimulus set. We then took the difference between these two differences and, using a one-tailed *t* test, determined whether or not the result was significantly different from zero. The visual field × spatial frequency interaction approached significance [$t(6) = 1.77, p < .06$]. The trend of visual field differences was the same as for the percent correct identification data; that is, there were no differences in the low-frequency condition (Figure 4C) and an RVF advantage in the high-frequency condition (Figure 4D). None of the other interactions were significant.

Thus, there is partial support for the spatial frequency hypothesis in both the contrast threshold percent correct identification and the RT data. High spatial frequencies are identified more accurately and more rapidly with RVF/LH than with LVF/RH presentations. However, there is an absence of a double dissociation (i.e., RH advantage for low frequencies and LH advantage for high).

EXPERIMENT 4

Suprathreshold Grating Identification

In Experiment 4, briefly flashed, suprathreshold sinusoidal gratings were presented and RT alone was measured. If a double dissociation exists at suprathreshold levels, then low-spatial-frequency gratings should be identified faster when presented in the LVF, since the RH is hypothesized to process these components more efficiently, and vice versa for high-spatial-frequency gratings.

Method

Subjects. Five right-handed males participated for course credit. Data from an additional subject were excluded because of failure to follow instructions.

Stimuli. Vertically oriented sinusoidal gratings (1 and 9 c/deg) were presented at contrast levels of .1, .2, and .4. The gratings were exposed for either 50 or 200 msec and were presented at a variable foreperiod (500–1,100 msec) after a brief warning tone.

Procedure. There were 20 replications of each condition and two rest periods within the experimental session. Each observer had a series of practice trials.

Half of the subjects depressed the left key for the wide-striped stimulus and the right key for the narrow-striped stimulus. For the other half, the reverse arrangement was used. For both groups, the importance of speed and accuracy was stressed as well as the importance of maintaining fixation.

Results and Discussion

A four-factor repeated measures ANOVA (2 spatial frequencies × 2 visual fields × 2 durations × 3 contrasts) was done on the basis of the means of the median RT for each condition for the 5 observers. The data were collapsed over duration, which did not significantly interact with the other three variables, and are presented in Figure 5 for the 1- and 9-c/deg gratings.

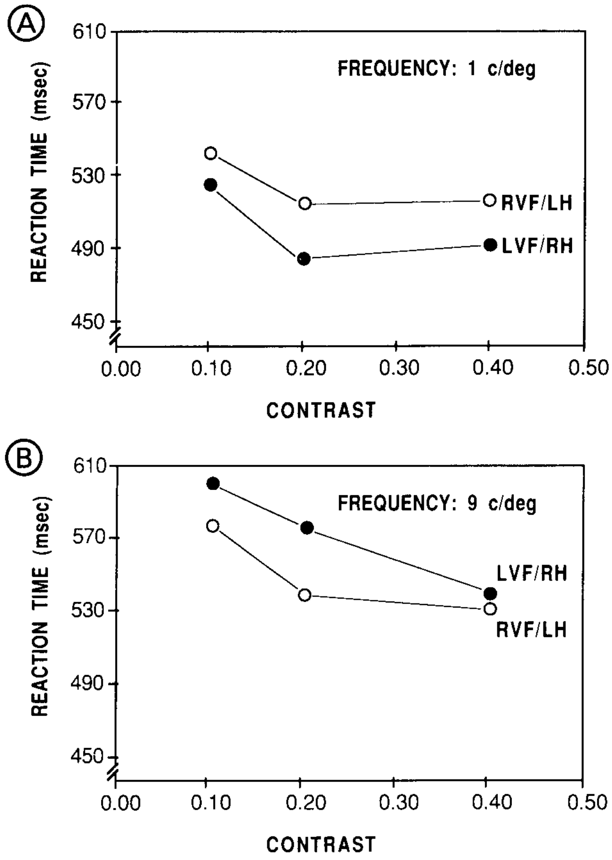

Figure 5. Reaction times to identify 1- and 9-c/deg gratings as a function of contrast level for left visual field/right hemisphere (LVF/RH, filled circles) and right visual field/left hemisphere (RVF/LH, open circles) presentations averaged over exposure duration.

Mean RT decreased with contrast [$F(2,6) = 32.41$, $p < .001$] and increased with spatial frequency [$F(1,4) = 14.8$, $p < .025$]. The visual field × spatial frequency interaction was significant [$F(1,4) = 8.03, p < .05$], as was the visual field × spatial frequency × contrast interaction [$F(2,10) = 7.06, p < .05$]. With the 1-c/deg grating, mean RTs were significantly faster when the presentation was in the LVF than when it was in the RVF [501 vs. 521 msec; $F(1,4) = 6.97, p < .05$]; with the 9-c/deg grating, they were faster when the presentation was in the RVF than when it was in the LVF [551 vs. 570 msec; $F(1,4) = 82.78, p < .01$]. The divergence increased with contrast for the 1-c/deg grating but decreased with contrast for the 9-c/deg grating (Figure 5).

In summary, the results of Experiment 4 are consistent with the spatial frequency hypothesis. A low-frequency grating was identified more rapidly in the LVF, and a high-frequency grating, more rapidly in the RVF. Mean RTs decreased with increases in contrast; the rate of decrease, however, depended on spatial frequency. It was faster and asymptoted sooner for the low-spatial-frequency gratings.

EXPERIMENT 5

The spatial frequency × visual field × contrast interaction in Experiment 4 strongly supports the hypothesis that the relative processing efficiency of the cerebral hemispheres depends on the spatial frequency of the stimulus. Exposure duration was not found to interact with spatial frequency and visual field. However, only two exposure durations were used. Therefore, a second suprathreshold experiment was conducted, utilizing the same spatial frequencies (1 and 9 c/deg) to examine the effects of exposure duration in more detail. Because it used the same spatial frequencies, Experiment 5 essentially replicated Experiment 4 and thus also provided a measure of the reliability of our findings.

Method

Subjects. Ten right-handed males participated for course credit.

Stimuli. The spatial frequencies of 1 and 9 c/deg were exposed for 20, 40, or 160 msec. The contrast of the gratings was .1, .2, or .4, and the mean luminance was 10 cd/m^2.

Procedure. The procedure used was similar to that used in Experiment 4. There were 20 repetitions of each combination of condition, and the analysis was based on the mean of the median RTs of each condition.

Results

Mean RT is plotted as a function of exposure duration for the 1- and 9-c/deg gratings (Figure 6). Filled circles plot the data for LVF presentations and open circles for RVF presentations.

As predicted from Experiment 4, spatial frequency interacted with visual field [$F(1,9) = 5.92, p < .05$]. The 1-c/deg grating evoked faster RTs when it was presented in the LVF, whereas faster RTs were obtained with the 9-c/deg target when it was presented in the RVF. There were no significant second-order interactions between duration, spatial frequency, and visual field. However, duration had a main effect [$F(2,18) = 9.54, p < .001$], and it interacted with spatial frequency [$F(2,18) = 4.84, p < .02$]. Mean RT decreased with exposure duration, especially with the 1-c/deg grating.

GENERAL DISCUSSION

In the initial formulation of the spatial frequency hypothesis, Sergent (1982) attributed hemispheric asymmetries in sensitivity to spatial frequency to processing beyond the sensory level. Earlier studies, in which gratings were used and in which no hemispheric asymmetries in contrast sensitivity were found, typically required detection and measured contrast at threshold levels. Failure to find hemispheric differences may be due to the level of stimulation; that is, hemispheric asymmetries may arise only at suprathreshold contrast levels. Conversely, failure to find hemispheric asymmetries may be due to the nature of the detection task. We addressed this issue in our experiments by varying both the level of stimulation (i.e., threshold vs. suprathreshold) and the nature of the task (detection vs. identification). We have shown that hemispheric asymmetries arise at both threshold and suprathreshold levels for grating identification. Conversely, hemispheric symmetry is found at both levels for grating detection.

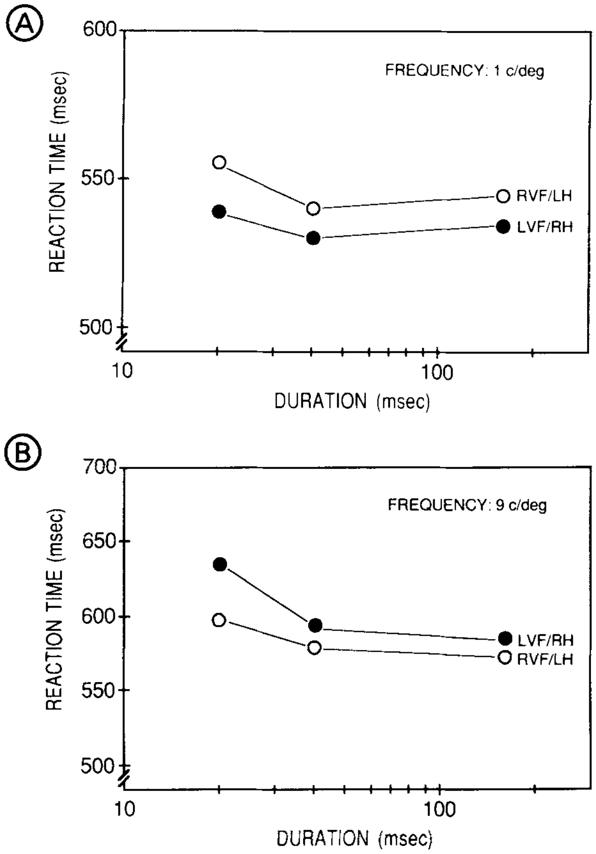

Figure 6. Reaction times to identify 1- and 9-c/deg gratings at 10% contrast as a function of exposure duration for left visual field/right hemisphere (LVF/RH, filled circles) and right visual field/left hemisphere (RVF/LH, open circles) presentations.

Hemispheric asymmetries in the processing of spatial frequency are not unique to our procedure, namely presenting a single sinusoidal grating in isolation and requiring a unique identification response. Christman, Kitterle, and Hellige (1990) found that compound gratings with low-spatial-frequency components (.5 and 1 c/deg) were identified faster by the RH than by the LH, whereas a compound grating with high-spatial-frequency components (4 and 8 c/deg) was identified faster by the LH than by the RH. Kitterle, Christman, and Hellige (1990) have shown that the direction of visual field asymmetries for compound gratings can be altered by choosing tasks that direct attention to either high- or low-spatial-frequency components. Finally, as noted earlier, a visual field × spatial frequency interaction is found in the time required to discriminate whether two successively presented gratings have the same or different spatial frequencies (Kitterle, 1990).

The results of the present experiments, together with the studies mentioned above, provide compelling evidence in support of the spatial frequency hypothesis. hemispheric asymmetries in identification in the direction predicted by this hypothesis can be induced either by changing the spatial frequency components of the visual input toward the high- or low-spatial-frequency range or by directing attention toward the high- or low-spatial-frequency components in the visual stimulus.

Recent models suggest that threshold detection and identification operate at the same level of sensory input but differ in the nature of the decision process (see Kitterle & Christman, in press, for further discussion). Sergent's (1982) statement that the hemisphere × spatial frequency interaction is the result of "processing beyond the sensory level" may be understood in terms of differences in the computational process for detection versus identification rather than differences in level of processing (i.e., detection early, identification late). Having clearly shown in our experiments that hemispheric asymmetries occur with identification tasks, we suggest that future work should be directed toward an elaboration of the nature of hemispheric differences in the computational processes involved in the identification of low versus high spatial frequency.

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