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Hemispheric sensitivity to spatial frequencies

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This experiment examined possible hemispheric differences in sensitivity to spatial frequencies. The experiment comprised two reaction-time tasks, the *same-different* matching of gratings and the enumeration of bars within a grating. Although little evidence was found for an interaction between visual field of presentation and spatial frequency, the obtained field differences always favored a left visual field advantage. In addition, such an advantage was found regardless of whether the processing took place at apparent sensory or at cognitive levels. It is concluded that prior studies supporting the theory of hemispheric asymmetry in spatial-frequency processing are methodologically insufficient, and that any further such research efforts should include a focus on higher frequencies and on stimulus degradation effects.

A current theory of hemispheric differences in visual perception is that the two hemispheres differ in sensitivity to spatial frequency.[1] In simplest terms, the right and left hemispheres are proposed to be most sensitive to low and high frequencies, respectively.

In what may be the earliest formulation of the theory, Sergent (1982a) stated,

> There are indications that the hemispheres are differentially sensitive to the level of sensory resolution received from sensory areas. Sensory resolution is expressed in terms of spatial frequency ... independently of the verbal or nonverbal nature of the stimuli and of the processes involved. (p. 161)

Thus the emphasis in this early formulation was on information received by the hemispheres from sensory (presumably peripheral) areas, and on independence from higher-order processes.

Sergent (1982c) quickly refined her theory, however, to reflect hemispheric differences at a "cognitive" level rather than a sensory level. She wrote,

> It is noteworthy that experiments on detection and integration time of spatial frequencies presented outside the fovea have yet reported no difference.... This may indicate similar extracting and integrating processes in the *sensory* areas of the right and left hemispheres. (p. 452)

Then, in discussing an apparent right hemisphere (RH) advantage in the processing of low frequencies, she stressed that what seemed to be involved was "the 'cognitive' processing taking place beyond the sensory areas, and in such conditions the RH proved to be better equipped" (p. 458).

Because of the distinction made between sensory and cognitive levels of processing, we conducted a study to contrast the two. The sensory-level task was the *same-different* matching of gratings, a task previously found to show no linkage between hemispheric differences and spatial frequency (Szelag, Budohoska, & Koltuska, 1987). The cognitive-level task was the enumerating of bars present in gratings. The cognitive nature of enumeration is defensible on two bases proposed by Sergent (1982b, 1982c). First, studies indicate that the enumeration of visual stimuli is impaired by RH temporal and parietal lesions (Kimura, 1963; Warrington & James, 1967). These lesions are well beyond the visual sensory areas, so enumeration represents a cognitive task using an anatomically defined criterion proposed by Sergent (1982c). Similarly, Sergent (1985) used face recognition as a task to show hemispheric spatial-frequency effects, and impairment of face recognition has a basis in RH temporal and occipital lesions (Meadows, 1974). Thus, both tasks have equivalent claims to be cognitive by an anatomical criterion. Second, enumeration typically results in RH advantage (Boles, 1986; Kimura, 1966; McGlone & Davidson, 1973; Teng & Sperry, 1974; Young & Bion, 1979), which converges on the task's use as a cognitive task in Sergent's usage. As she has claimed (1982b), "hemispheric asymmetries emerge ... only when cognitive operations are performed" (p. 254).

METHOD

Subjects

A total of 32 subjects were used. All were right-handed by self-report and received extra credit in a course for their participation. Half were assigned to a near and half to a far viewing condition. Since a preset overall criterion of 60% correct per task was used (weighting *same* and *different* trials equally), an additional 8 subjects were rejected for low accuracy in one or both tasks used in the experiment.

Apparatus and Stimuli

Square-wave gratings were displayed on an Apple Monitor III with a black-and-white (P4) phosphor, controlled by an Apple IIe computer. Grating intensities were constant and well above threshold, and the ex-

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periment was run under near-dark viewing conditions. Viewing distance was controlled by using a chinrest; the distances in the near and far conditions were 0.47 and 3.79 m, respectively.

The gratings were switched on from a dark field. They were presented with their bars oriented horizontally, and subtended 7.4° and 0.9° horizontally in the near and far conditions, respectively. When shown in one visual field, a grating appeared with its near edge 3.9 cm from the fixation point, representing eccentricities of 4.7° and 0.6° at the near and far distances, respectively. These dimensions were selected so that the monitor screen was divided into three slightly separated zones, one for each visual field and one for the central presentation of a grating. Further details concerning the stimuli depended on the task, as follows.

Matching task. In the vertical dimension, gratings subtended between 14.8° and 15.4° in the near condition, and between 1.8° and 1.9° in the far condition. This slight variation within a distance was unavoidable since the vertical extent is not fully independent of frequency. Five different bar widths/spacings were used, producing five different spatial frequencies at each distance. At the near distance, the frequencies were 0.5, 0.6, 0.8, 1.3, and 2.5 cycles per degree (cpd). At the far distance, they were 4.0, 5.0, 6.6, 10.1, and 20.0 cpd.

Enumeration task. Compared with gratings in the matching task, gratings in the enumeration task were reduced in the range of frequencies used and in their vertical extent, to produce from one to six bars per grating. The frequencies used were 0.5 and 0.6 cpd at the near distance, and 4.0 and 5.0 cpd at the far distance. Depending on the frequency and number of bars, the gratings varied in vertical extent from 0.8° to 10.8° at the near distance, and from 0.1° to 1.3° at the far distance.

Procedure

Each subject performed both the matching and enumeration tasks, in balanced order across subjects. In both tasks, responses were made on two-key boards, with the keys oriented in the midline (one nearer to and one farther from the subject). Hand response was balanced, such that half the subjects used the right hand on the *same*/odd key and the left hand on the *different*/even key, with the assignments reversed for the other subjects. The instructions emphasized both the speed and the accuracy of responses. In both tasks, a 3-sec response deadline was imposed, and brief feedback was given on the speed and the accuracy of responses.

Matching task. A trial in the matching task began with a 300-msec presentation of a grating in the central field, followed by a 100-msec blank period, a central fixation cross for 1,500 msec, another 100-msec blank, and then a bilateral display for 100 msec. The bilateral display was composed of a grating in one visual field, to be matched with the first (central) grating, a central arrowhead (< or >) pointing to that grating, and a randomly selected distractor grating in the opposite visual field. A similar bilateral method with central arrowhead has been shown to be effective in producing both left visual field (LVF) and right visual field (RVF) asymmetries (as appropriate) in reaction time (RT) tasks (Boles, 1987).

The task thus required the successive matching of a pair of gratings. Pairs were selected such that two-thirds were *same* and one-third were *different*, with the *same* pairs selected equally from all of the employed spatial frequencies. Trials were organized in blocks of 60, with one practice block followed by five experimental blocks.

Enumeration task. In the enumeration task, a trial started with a 750-msec presentation of a central fixation cross, followed by a 100-msec blank and then a 100-msec bilateral display. As in the matching task, a central arrowhead pointed to the grating to which subjects were to respond, and a randomly selected grating was shown as a distractor in the opposite visual field.

The task required enumerating the bars in a grating as "odd" (1, 3, or 5 bright bars) or "even" (2, 4, or 6 bright bars). Half of the trials were of each type, and the spatial frequencies employed were equally sampled. Trials were in blocks of 48, with one practice block followed by five experimental blocks.

RESULTS

Matching Task RT

Figure 1 illustrates the *same*-match results. Median RTs were calculated for the correct responses and subjected to analysis of variance (ANOVA), using the factors visual field and spatial frequency. In the near condition, there was only one significant effect, that of spatial frequency [$F(4,60) = 8.66, p < .001$]. The visual field effect and the visual field × spatial frequency interaction were not significant (both ps $> .2$). As can be seen in Figure 1, the spatial frequency effect appears to be due to very fast RTs in the 2.5 cpd condition. In the far condition, there were no significant effects. The term that came closest was that of visual field × spatial frequency [$F(4,60) = 2.21, p = .08$]. As shown in Figure 1, there was a trend toward an increasing LVF advantage with increasing spatial frequency.

Examination of Figure 1 suggests the existence of a LVF advantage for the two highest spatial frequencies in the near and far groups combined. If distance is made a factor and an ANOVA is run on the combined groups, this trend is confirmed by a significant visual field × spatial frequency interaction [$F(4,120) = 2.73, p < .05$]. Decomposition indicates that the fourth spatial frequency in each group (1.3 and 10.1 cpd) produced a significant LVF advantage [$t(31) = 2.75, p = .01$], and the fifth spatial frequency (2.5 and 20.0 cpd) produced a marginally significant LVF advantage [$t(31) = 1.96, p < .10$]. The other spatial frequencies did not (all ts < 1). Note, however, that this is not a true linkage of visual field differences to spatial frequency since the effect existed at both viewing distances; that is, it is more appropriate to say that a LVF advantage was found for gratings with a large number of bars, regardless of spatial frequency.

Different trials could not be split by spatial frequency except by near versus far condition, since *different* pairs

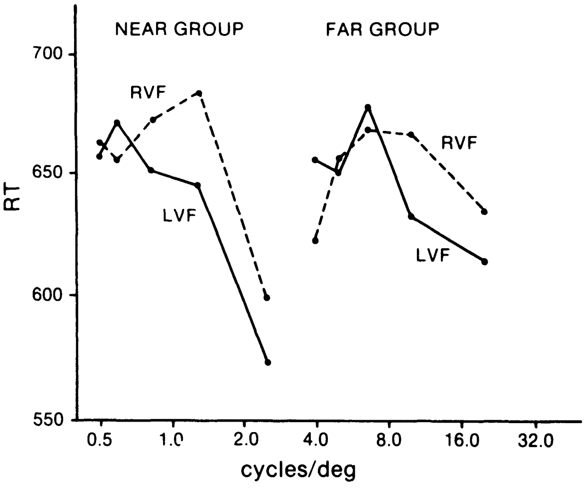

Figure 1. Same-pair reaction times (RTs) from the matching task.

were always of differing spatial frequencies. Accordingly, RTs to *different* trials were analyzed for the combined distance groups in an ANOVA with the factors of visual field and distance. No effects were significant (all *p*s > .2). The mean RT for *different* trials was 748 msec.

Matching Task Errors

Percentages of errors on *same* matches were subjected to a combined ANOVA using the factors of visual field, spatial frequency, and distance. No terms were significant (all *p*s > .1). An analysis run on percentage of errors for *different* matches likewise showed no significant effects. Overall error rates were 13.5% for *same* matches and 34.8% for *different* matches, a disparity no doubt attributable largely to the 2:1 ratio of *same* to *different* trials, which would create a "same" response bias.

Enumeration Task RT

Figure 2 illustrates the results from the enumeration task. ANOVAs were run using the factors of visual field and spatial frequency. In the near condition, the only significant effect was that of visual field [$F(1,15) = 4.57$, $p < .05$]. The LVF was faster by 23 msec. Likewise, in the far condition, visual field was the only significant effect [$F(1,15) = 7.51$, $p < .02$]. The LVF was faster by 21 msec. If a combined analysis is run using distance as a factor, visual field exerts a main effect [$F(1,30) = 11.07$, $p = .002$], but there is no visual field × distance interaction ($F < 1$). There also is no main effect of distance [$F(1,30) = 2.20$, $p > .10$].

Enumeration Task Errors

Percentages of errors were subjected to a combined ANOVA using the factors of visual field, spatial frequency, and distance. All three main effects, and only the main effects, were significant ($F < 1$ for all interactions). The LVF produced fewer errors than the RVF [21.1% vs. 23.3%; $F(1,30) = 4.48$, $p < .05$]. The near condition produced fewer errors than the far condition [19.2% vs. 25.2%; $F(1,30) = 5.12$, $p < .05$], and across distance conditions, the lower spatial frequency (0.5 and 4.0 cpd) produced fewer errors (21.0%) than the higher spatial frequency [0.6 and 5.0 cpd, 23.4%; $F(1,30) = 4.99$, $p < .05$].

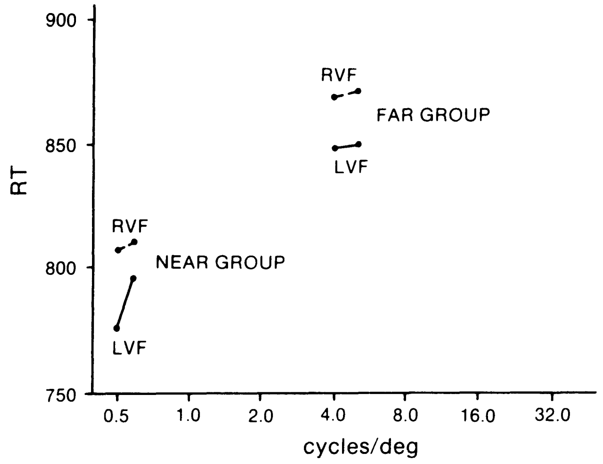

Figure 2. Reaction times (RTs) from the enumeration task.

DISCUSSION

As anticipated, the present matching task produced no trace of a visual field × spatial frequency interaction that in any way supports a linkage of hemisphere asymmetry and spatial frequency. There was some indication of a LVF advantage at the two highest spatial frequencies at each viewing distance, that is, at 1.3 and 2.5 cpd at the near distance, and at 10.1 and 20.0 cpd at the far distance.

The most important results are from the enumeration task, representing the cognitive task in the experiment. Again, no evidence was found in support of a hemispheric association to spatial frequency. Instead, a general LVF advantage was found, replicating the reported LVF advantage for the enumeration of nonverbal items (Boles, 1986; Kimura, 1966; McGlone & Davidson, 1973; Teng & Sperry, 1974; Young & Bion, 1979). The effect was quite independent of spatial frequency. Indeed, it is noteworthy that the spatial frequencies that produced a LVF advantage in the enumeration task (0.5 and 0.6 cpd at the near distance, and 4.0 and 5.0 cpd at the far distance) failed to produce any visual field difference in the matching task. Clearly, the spatial-frequency theory of hemispheric asymmetry cannot account for the results from either.

The major prediction of the spatial-frequency theory of hemispheric differences is that the right hemisphere should be more sensitive to low frequencies and the left hemisphere to high frequencies. When field differences were found in the two tasks, however, they always favored the LVF (right hemisphere). This generalized LVF advantage was most consistent in the enumeration task. It also was found in the matching task, manifested as a LVF advantage at the two highest spatial frequencies in each distance group. That the LVF superiority was found at the highest frequencies runs directly counter to Sergent's (1982c) theory. Thus there is little evidence overall in support of the theory, regardless of whether one views the predicted effects as residing at the sensory or at the cognitive level.

It is worth noting that any contamination of the fundamental frequencies of the square-wave gratings by their harmonics cannot account for the present results. This is because the harmonics of a fundamental frequency are always higher than that frequency. According to the hemispheric theory, any contamination by harmonics should therefore shift visual field differences toward the RVF. No evidence of any RVF advantage appears in this experiment. In fact, taking the two tasks collectively, LVF advantages appeared across the spectrum of fundamental frequencies.

Also worth noting is that the results cannot be attributed to the two viewing distances used in the study. It was the longer viewing distance, and thus the higher frequencies, that had the smallest minimum eccentricity (0.6°). However, as pointed out by Sergent (1982a), reduced eccentricity as opposed to increased eccentricity is a condition that favors the extraction of high frequencies. Thus, the conditions were nearly optimal for finding a RVF advantage for the high frequencies, but no such advantage was found. Nor can it be claimed that such a small eccentricity obviates the finding of visual field effects, because (1) such effects were found, and (2) studies have demonstrated the validity of small eccentricities in uncovering hemispheric differences (Harvey, 1978; Haun, 1978).

To emphasize these points, the use of square-wave gratings presented at small eccentricities should have provided an excellent environment for the emergence of a RVF advantage for high spatial frequencies. That a LVF advantage was instead found is a serious problem for the hemispheric spatial-frequency theory, particularly since filtering studies cited in support of the theory have not adequately addressed visual field differences at high frequencies (Jonsson & Hellige, 1986; Sergent, 1985). We suggest that findings that appear to be supportive of the theory, such as those relative to stimulus filtering and blurring, might best be viewed as the result of stimulus degradation and not as the result of spatial-frequency manipulations. At the very least, it seems reasonable to propose that the design of experiments seemingly in support of the theory be completed by demonstrating a RVF (left hemisphere) shift under conditions favoring high spatial frequencies. A LVF (right hemisphere) advantage appears too ubiquitous to stand alone without showing a crossover interaction.

REFERENCES

BOLES, D. B. (1986). Hemispheric differences in the judgment of number. *Neuropsychologia*, **24**, 511-519.

BOLES, D. B. (1987). Reaction time asymmetry through bilateral vs. unilateral stimulus presentation. *Brain & Cognition*, **6**, 321-333.

HARVEY, L. O. (1978). Single representation of the visual midline in humans. *Neuropsychologia*, **16**, 601-610.

HAUN, F. (1978). Functional dissociation of the hemispheres using foveal visual input. *Neuropsychologia*, **16**, 725-733.

JONSSON, J. E., & HELLIGE, J. B. (1986). Lateralized effects of blurring: A test of the visual spatial frequency model of cerebral hemisphere asymmetry. *Neuropsychologia*, **24**, 351-362.

KIMURA, D. (1963). Right temporal-lobe damage. *Archives of Neurology*, **8**, 264-271.

KIMURA, D. (1966). Dual functional asymmetry of the brain in visual perception. *Neuropsychologia*, **4**, 275-285.

MCGLONE, J., & DAVIDSON, W. (1973). The relation between cerebral speech laterality and spatial ability with special reference to sex and hand preference. *Neuropsychologia*, **11**, 105-113.

MEADOWS, J. C. (1974). The anatomical basis of prosopagnosia. *Journal of Neurology, Neurosurgery, & Psychiatry*, **37**, 489-501.

SERGENT, J. (1982a). Basic determinants in visual-field effects with special reference to the Hannay et al. (1981) study. *Brain & Language*, **16**, 158-164.

SERGENT, J. (1982b). The cerebral balance of power: Confrontation or cooperation? *Journal of Experimental Psychology: Human Perception & Performance*, **8**, 253-272.

SERGENT, J. (1982c). Theoretical and methodological consequences of variations in exposure duration in visual laterality studies. *Perception & Psychophysics*, **31**, 451-461.

SERGENT, J. (1985). Influence of task and input factors on hemispheric involvement in face processing. *Journal of Experimental Psychology: Human Perception & Performance*, **11**, 846-861.

SZELAG, E., BUDOHOSKA, W., & KOLTUSKA, B. (1987). Hemispheric differences in the perception of gratings. *Bulletin of the Psychonomic Society*, **25**, 95-98.

TENG, E. L., & SPERRY, R. W. (1974). Interhemispheric rivalry during simultaneous bilateral presentation task presentation in commissurotomized patients. *Cortex*, **10**, 111-120.

WARRINGTON, E. K., & JAMES, M. (1967). Tachistoscopic number estimation in patients with unilateral cerebral lesions. *Journal of Neurology, Neurosurgery, & Psychiatry*, **30**, 468-474.

YOUNG, A. W., & BION, P. J. (1979). Hemispheric laterality effects in the enumeration of visually presented collections of dots by children. *Neuropsychologia*, **17**, 99-102.

NOTE

1. The term *sensitivity* is used here in its broad sense, as responsivity to a spatial frequency. This usage should cause no problems of interpretation, as long as it is recognized that increased sensitivity can be manifested in many ways (e.g., as reduced reaction times or increased detection of flicker), not only in the narrow sense of a lowered contrast threshold.

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