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Simple reaction times to the onset, offset, and contrast reversal of sinusoidal grating stimuli

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Response latencies to the onset, offset, and contrast reversal of sinusoidal gratings over a range of spatial frequencies were measured. For gratings of constant physical contrast, RT was monotonically related to spatial frequency regardless of presentation mode. Comparison of RTs to 1.0- and 9.0-cycle/deg gratings adjusted to equal apparent contrast showed that the RT shifts cannot be directly attributed to contrast sensitivity differences. It is concluded that spatial-frequency-dependent processing delays occur regardless of which temporal property of the stimulus the subject must respond to.

Studies on simple reaction times (RTs) to visual patterns indicate that spatially coarse patterns elicit faster responses than do spatially fine patterns (Breitmeyer, 1975; Kaswan & Young, 1965; Lupp, Hauske, & Wolf, 1976; Vassilev & Mitov, 1976). RTs to sinusoidal gratings of constant contrast increase approximately monotonically with increasing spatial frequency (Breitmeyer, 1975; Lupp et al., 1976; Vassilev and Mitov, 1976), and equating the apparent contrast of the grating reduces, but does not abolish, the RT differences (Breitmeyer, 1975). Using electrophysiological measures, Parker and Salzen (1977a, 1977b) reported that the peak latency of all evoked response components elicited by the onset of sinusoidal gratings show progressive delays with increasing spatial frequency. These differences are not abolished by equating the apparent contrast of the gratings (Vassilev & Strashimirov, 1979) or by generating constant amplitude responses at the different spatial frequencies (Jones & Keck, 1978). It has been proposed that the RT shift reflects a change from a fast conducting transient system (Y cell) optimally sensitive to low spatial frequencies to a slower conducting sustained system (X cell) with greater sensitivity at intermediate and high spatial frequencies (Breitmeyer, 1975). When low-contrast stimuli are employed, there is indeed evidence that different systems are involved in initiating responses to low and high spatial frequencies (Harwerth & Levi, 1978; Lupp, Hauske, & Wolf, 1978). However, at medium and high contrasts, responses may be initiated by a single class of channel over a wide range of spatial frequencies, and yet, RT shifts still occur (Harwerth & Levi, 1978). Indeed, using low-contrast gratings, Lupp et al. (1978) found that, while the temporal response profiles to 5.3- and 16.0-cycle/deg gratings showed the characteristics of the sustained system, the profile of the higher spatial frequency is relatively delayed. Spatial-frequency-dependent processing delays may then be an extremely general feature of visual processing occurring within, as well as between, different classes of channels (Parker & Salzen, 1977a). If spatial-frequency-dependent delays are indeed an extremely basic feature of visual processing, then they should be apparent in circumstances in which the subject must respond to some temporal property of the stimulus other than its onset. The present report examines RTs to the onset, but also to the offset, and contrast reversal of sinusoidal gratings.

I would like to thank Gail Garnsworthy for her help in gathering the data for these experiments.

METHOD

Vertical sinusoidal gratings were generated on a Tektronix Model 604 display oscilloscope. The gratings could be turned on and off or contrast reversed without altering the mean luminance of the screen (10 cd/m²). The screen was masked to produce a 6-deg circular stimulus area when viewed from 1.0 m and had a central fixation spot. The mask was illuminated so that it was maintained at the same mean luminance and color as the screen. Viewing was binocular. Stimulus duration was 400 msec with an interstimulus interval of 2.5 sec added to what was a random delay of 0-200 msec. RTs were collected in blocks of 40 for each subject for each spatial frequency condition, the order being randomized with the proviso that the same spatial frequency not be used for the same subject in two successive blocks of trials, e.g., the 1-cycle/deg (c/d) onset condition did not follow the 1-c/d offset condition. RTs were collected on a printout countertimer. Each subject was familiarized with the range of spatial frequencies to be used in the experiment and was given a block of practice trials in which different spatial frequencies were presented. The subjects in all conditions were urged to respond as rapidly as possible, no stress being placed on the avoidance of false responses. In fact, anticipatory responses (those less than 150 msec) were less than 2%.

Experiment 1

Three right-handed male subjects participated in the experiment, which examined RTs to the onset and offset of gratings of differing spatial frequencies. In onset conditions, the grating replaced the blank screen, while in offset conditions, the grating was

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present during the interstimulus interval and was replaced by a blank screen for 400 msec. Trials were run at 1, 3, 6, 9, and 12 c/d, the subjects being instructed to respond as quickly as possible to the onset or offset, respectively. The contrast of the grating was .21, contrast = L max − L min divided by 2L mean, where L is the luminance of any point on the screen.

Experiment 2

Three right-handed male subjects participated in an experiment that examined RTs to contrast reversal of sinusoidal gratings. Gratings were visible throughout the experimental trial, the stimulus for subject response being an abrupt 180-deg phase shift of the grating, which reset its original position after 400 msec. Trials were run at 1, 3, 6, and 9 c/d at a contrast of .21 and .105, the 12-c/d condition being omitted when it became clear that, at the lower contrast, RTs were so long (600-1,000 msec) that it could not be established whether subjects were reacting to the initial contrast reversal or to the reset.

Experiment 3

Six right-handed male subjects took part. The experiment examined RTs to onset, offset, and contrast reversal at two spatial frequencies, 1 and 9 c/d. For the onset, offset, and high-contrast reversal conditions, the 1.0-c/d grating was set at a contrast of .2 and the 9.0-c/d grating was set at a value of .27. For the low-contrast reversal condition, these values were halved. This 35% increase to match a 9.0-c/d grating with one of 1.0 c/d agrees with the contrast matching data of Blakemore, Muncey, and Ridley (1973) and, in fact, overestimates the sensitivity differences between the two spatial frequencies (Campbell & Green, 1965).

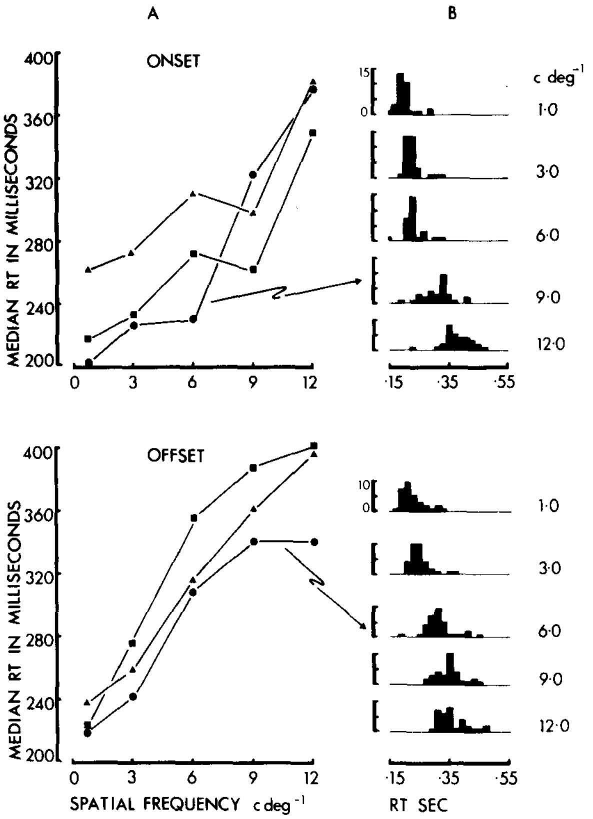

Figure 1. (A) Reaction times to the onset or offset of sinusoidal gratings as a function of spatial frequency for three subjects. (B) RT distributions as a function of spatial frequency for the subject indicated.

RESULTS

RTs to Onset and Offset

The results of Experiment 1 are displayed in Figure 1A where median RTs for each subject are plotted. When subjects respond to the onset or the offset of sinusoidal gratings, RT is approximately monotonically related to spatial frequency. The median RTs for each block of trials for each subject were subjected to a within-subjects analysis of variance. The analysis indicated only a significant effect of spatial frequency [$F(4,8) = 66.6$, $p < .0001$], the difference between onset and offset [$F(1,2) = 4.45$, $p = .17$] and the interaction of onset and offset conditions with spatial frequency [$F(4,8) = 3.07$, $p = .0827$] proving nonsignificant. An example of the pattern of RT distributions can be seen displayed in Figure 1B, in which one subject's complete results are shown. It can be seen that, as well as a progressive shift in the RT distributions with spatial frequency, there is a spread in the distributions. Statistical analysis confirms that the means and standard deviations are correlated in the onset ($r = .72$) and offset ($r = .63$) conditions.

RT to Contrast Reversal

Median RTs as a function of spatial frequency at two levels of contrast are shown in Figure 2A. Over the range of spatial frequencies tested, there is an approximately monotonic relationship between median RT and spatial frequency. A within-subjects analysis of variance of the medians for each block of trials for each subject was carried out. The analysis revealed a highly significant effect of spatial frequency [$F(3,6) = 26.208$, $p = .0008$] but no effect of contrast [$F(1,2) = 3.14$, $p = .22$], and a nonsignificant Contrast by Spatial Frequency interaction [$F(3,6) = 3.39$, $p = .095$]. In Figure 2B, examples of the complete RT distributions from one subject are displayed. Once again, there is a tendency for the spread of the RT distribution to increase with spatial frequency, although this correlation is more apparent in the low-contrast condition ($r = .88$) than in the high-contrast condition ($r = .23$).

RT to Equivalent Contrast Stimuli

The results of Experiment 3 are displayed in Figure 3. In RTs to onset, offset, and to high- and low-contrast reversal, the response latency to the 9.0-c/d grating was consistently and significantly longer (t tests of median RTs in the 1.0- and 9.0-c/d conditions for the six subjects, $p < .005$, $p < .01$, $p < .01$, $p < .005$, respectively). Comparison of the RTs in the two conditions—low-contrast reversal of the 1.0-c/d grating, high-contrast reversal of the 9.0-c/d grating—indicates that they differ significantly ($p < .025$). Thus, RTs to a 1.0-c/d grating with a contrast of .1 were faster than to a 9.0-c/d grating with a contrast

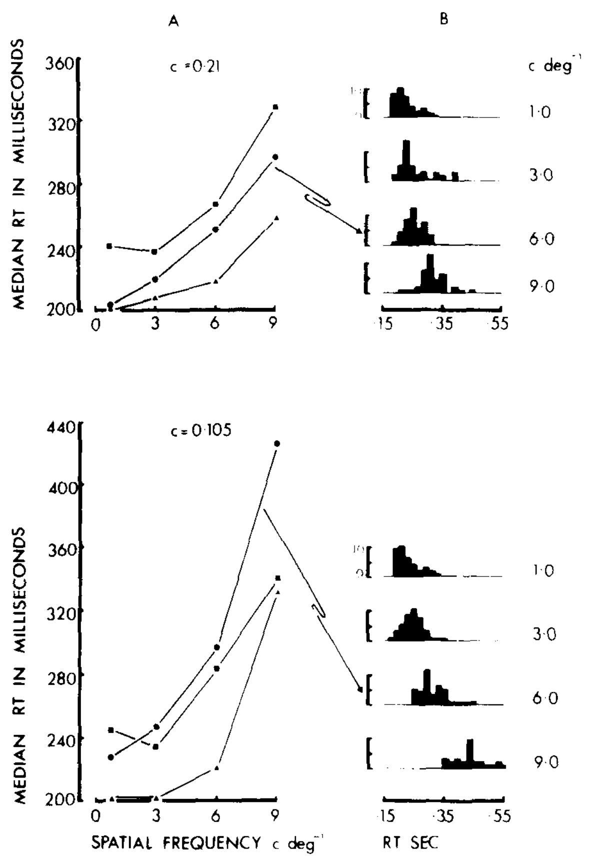

Figure 2. (A) Reaction times as a function of spatial frequency for three subjects. (B) RT distributions as a function of spatial frequency for the subject indicated.

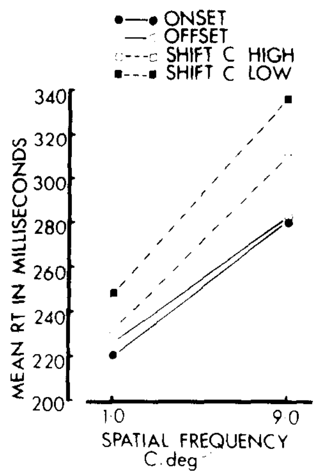

Figure 3. Reaction times to the onset, offset, and contrast reversal at two contrast levels at two spatial frequencies equated for apparent contrast. Points plotted are the means of the median scores for six subjects. SHIFT = contrast reversal.

of .27. No other comparison is significant except that between the 9.0-c/d onset condition and the 9.0-c/d low-contrast reversal condition ($p < .025$). The closeness of the RTs to onset and offset reinforces the results of Experiment 1, in which no significant difference was found between these conditions or in their interaction with spatial frequency. Inspection of the RT distributions showed that at 1.0 and 9.0 c/d they revealed a similar spread, and statistical analysis of the standard deviations at the two spatial frequencies showed no significant difference. In summary, then, RTs to 9.0-c/d gratings are significantly slower than to 1.0-c/d gratings, even when differences in sensitivity have been compensated for.

DISCUSSION

The main concern of this report is with the generality of the RT vs. spatial frequency function. The results of Experiment 1 confirm previous reports of a spatial-frequency-dependent delay in responding to the onset of sinusoidal gratings and also shows that a similar delay occurs when the subject must respond to the offset of the stimulus. Experiment 2 provides evidence that when patterns are contrast reversed (a mode of presentation that produces a strong sensation of abrupt movement of the pattern through 180 deg), there is again a significant spatial-frequency-dependent delay in RT. The results of Experiment 3 show that when sensitivity differences between spatial frequencies are compensated for, RTs to a 9.0-c/d grating are still significantly longer than to a 1.0-c/d grating, regardless of whether the subject responds to the onset, offset, or contrast reversal of the stimulus. In fact, the results of the contrast reversal condition indicate that RTs to a 1.0-c/d grating can be significantly faster than those to a 9.0-c/d grating whose contrast is greater by a factor of more than 2.5. It would appear reasonable to conclude that spatial-frequency-dependency response lags occur regardless of which temporal aspect of the stimulus the subject must respond to. Since these RT data were obtained with stimulus contrasts well in excess of threshold values, it is unlikely that the detection mechanisms were restricted to a single class of channel, either transient or sustained, at any point in the range of spatial frequencies tested. Responses may have been initiated by either class of channel or by a combination of both. There is some indication from previous research that pattern offset (Tolhurst, 1975) and contrast reversal (Kulikowski, 1978) should favor the operation of the transient channels, so it is possible that these made a greater contribution to response initiation under these conditions.

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