The Detection of Moving Features on a Display: The Interaction of Direction of Motion, Orientation, and Display Rate

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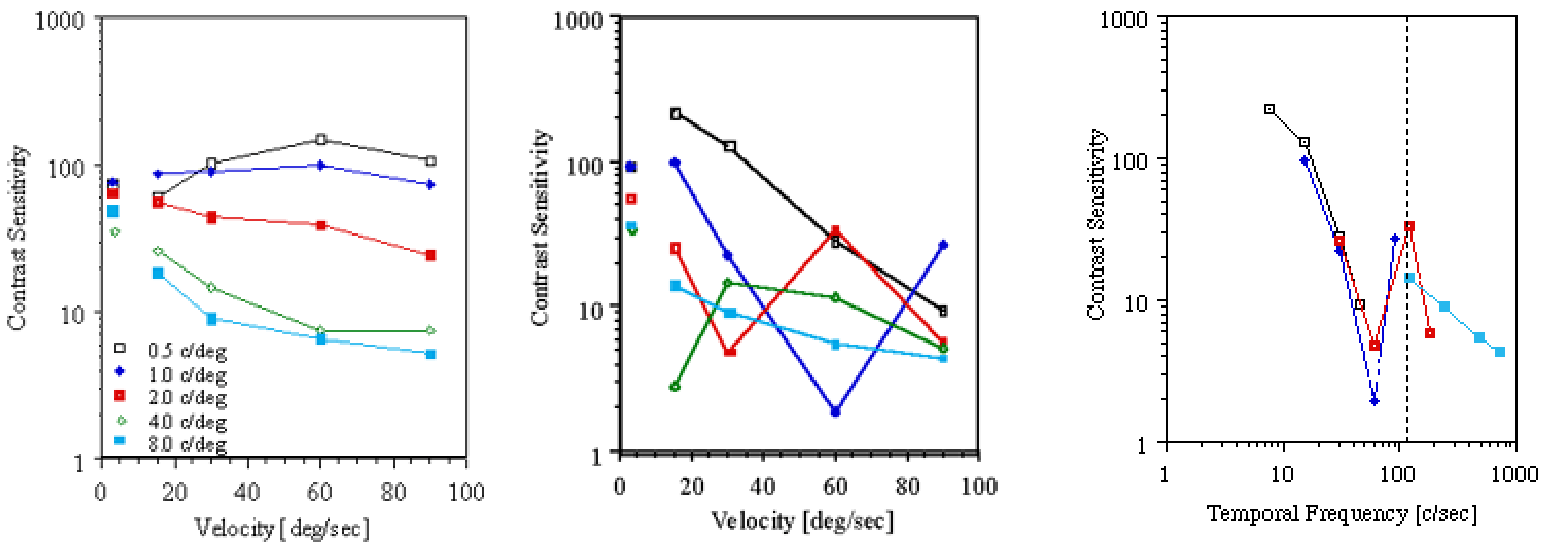
Abstract

The contrast detection thresholds for Gabor patches, as a function of speed, oscillated by as much as a log unit when the motion was orthogonal to the orientation of the Gabor. Sensitivity was mediated by temporal frequency alone. Parallel motion, wide-band stimuli, and eye tracking allowed for higher sensitivity.

Introduction

We studied how contrast sensitivity varies depending on the orientation and the direction of motion of stimulus features. Previous studies of contrast sensitivity for moving gratings (e.g. Koenderink et al., 1987; Hammet & Bex, 1996) have used full screen gratings for which only orthogonal movement is defined. We (Fine et al., 1996; Peli & Labianca, 1997) measured detection thresholds for Gabor patches oriented either horizontally (Ho) or vertically (Vo) and moving either in a horizontal (Hm) or vertical (Vm) direction.



a **b** **c**

Figure 1. The interaction of target orientation and direction of motion on contrast sensitivity for a Gabor patch. a) With parallel motion sensitivity is only moderately affected even at high velocities. b) With orthagonal motion, sensitivity oscillates with increased velocity. c) Data from 1b converged to a single pattern when plotted as a function of temporal frequency, illustrating a sharp dropin sensitivity with increased temporal frequency and an aliasing artifact when the display's Niquist rate is exceeded.

When the orientation of the Gabor was parallel to the direction of motion (e.g. HmHo), there was an orderly decrease in sensitivity as speed increased (Fig. 1a). However, when the orientation and direction of motion were orthogonal to each other (e.g. HmVo), sensitivity as a function of speed oscillated up and down by as much as 1 log unit (Fig. 1b). This oscillation in sensitivity was due solely to temporal sensitivity (spatial frequency ∞ speed), not speed or spatial frequency (Fig. 1c). Sensitivity for all spatial frequencies decreased sharply as a function of temporal frequency and then reversed at the Niquist rate (58.5 Hz for the 117 Hz monitor). The increase in sensitivity at higher speeds was a result of the interaction between the temporal frequency of the Gabor and the sampling rate of the display. The experiments reported here expand on these initial findings.

Methods

Stimuli were presented on a 117 Hz non-interlaced monochrome monitor (DP-104 phosphor; mean luminance 50 cd/m2; decay time 0.8 msec to 10% peak emission) driven by a VisionWorks™ system. The display spanned 16.3 ∞ 12.4 deg at 1 m with a resolution of 1024 ∞ 512. The calibrated screen provided a linear response over 3 log units.

Gabor patches of 0.7-octave bandwidth and the same mean luminance as the display were oriented either horizontally (Ho) or vertically (Vo). The center mean frequency of the Gabors was 0.5, 1.0, 2.0,4.0, or 8.0 c/deg. The targets moved either horizontally (right to left; Hm) or vertically (bottom to top; Vm) at one of 4 speeds: 15, 30, 60, or 90 deg/sec.

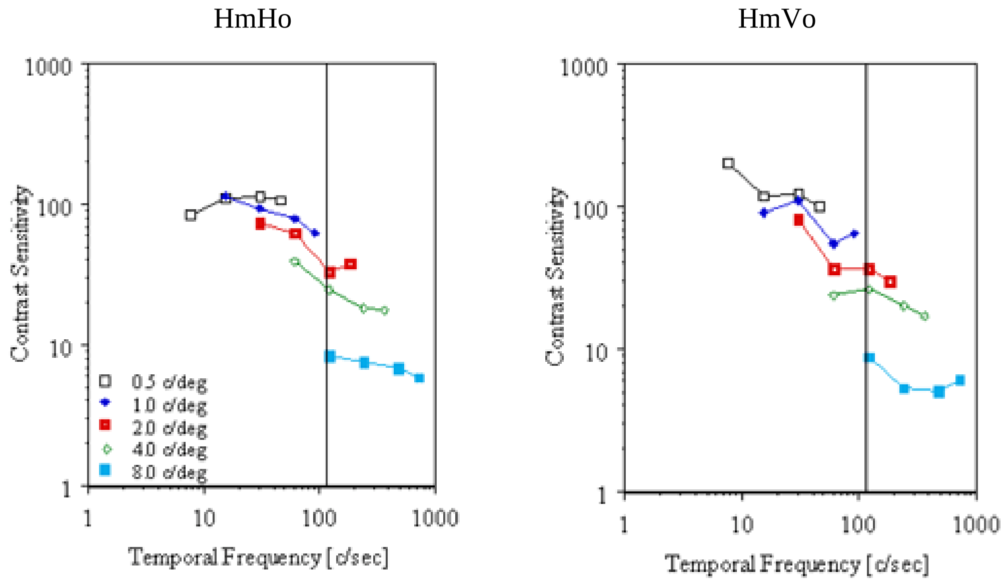


Figure 2. When the display is updated at one third of the refresh rate, aliasing artifacts at the lower rates also occur, resulting in a substantial increase in sensitivity with orthogonal motion.

Viewing was binocular in a dark room. Testing began following 5 min. of adaptation to the screen luminance. Seating distance was 1.0 m for the 8.0 c/deg patch and 0.5 m for the remaining stimuli except where indicated.

The target onset was preceded by a 250 msec tone. Because speed and direction were blocked, the subject always new the starting location and velocity of the target. Subjects were required to decide on each trial whether or not a target had appeared. Stimulus contrast changed by 20% for two practice reversals and 5% for 6 experimental reversals using a staircase procedure. Contrast threshold was defined as the average contrast of the 6 experimental reversals.

The experiments described in the Introduction and Exp. 1 were each repeated using a Nano color monitor (green gun only) with a P22 phosphor to determine if the effects reported here generalize to more common, slower phosphor displays. The decay time for this monitor was 6.0 msec to 10% of peak emission. There were no appreciable differences in the data using this monitor.

Experiment 1: Decreased Update Rate

When the update rate of the display was the same as the refresh rate (117 Hz), contrast sensitivity for the moving Gabors oscillated, reaching a trough at the Niquist rate and peaking again at the refresh rate of the display (Fig. 1). This experiment sought to replicate those findings using a slower update rate. In many applications, computing speed is insufficient to update the display every frame (Lindholm, 1992; Chen et al., 1993). For example, it was not possible to update the lowest frequency patch (0.5 deg) at the full refresh rate of the display system we used. Lindholm (1992) reported on the visual artifacts apparent with supra-threshold stimuli with a low update rate. Here we report on the effects of low update rate at threshold.

We used the methods described above with the following exceptions. Instead of updating the display every frame (update rate = 117 Hz), the Gabor remained stationary for three frames before moving on to its next location (update rate = 117 ÷ 3 = 39 Hz). Viewing distance was 1 m for all spatial frequencies. Figure 2 shows the HmHo and HmVo sensitivity data in terms of temporal frequency. As can be seen there, we replicated our earlier findings. The aliasing artifacts we found with the full update rate here occurred at both the Niquist rate defined by the update rate (19.5 Hz) and the Nyquist defined by the full refresh rate of the display (58.5 Hz). Except for this change in the aliasing transition point, there were no other qualitative differences between the two experiments. Note, however, that the aliasing artifact results in substantially higher sensitivity with the slower update rate.

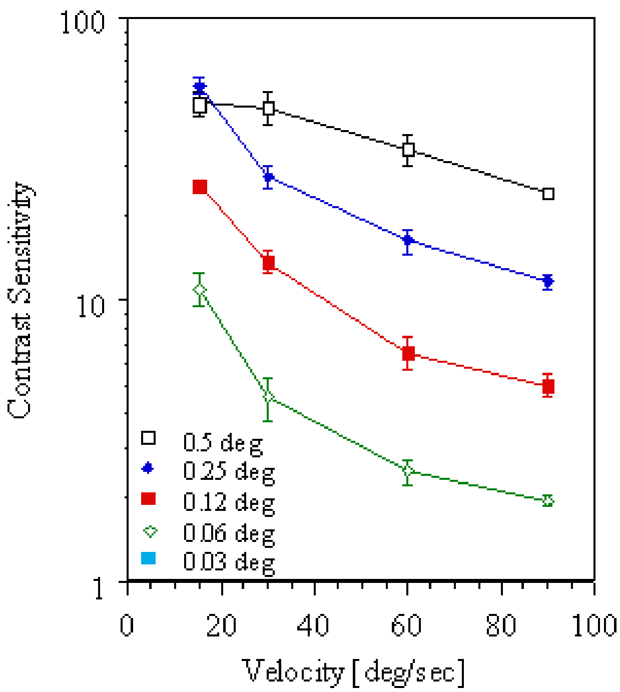
Experiment 2: Low-pass Stimulus–Gaussian Patch

In the parallel conditions, the Gabor patch is low-pass in nature, whereas in the orthogonal condition, it is band-pass. This results in a lower absolute bandwidth in the parallel condition. To determine if the low-pass nature of the stimuli in the parallel condition resulted in the increased sensitivity and lack of oscillation found in the previous experiments, we replicated the experiment at the full update rate using stimuli with low-pass characteristics in all directions.

Stimuli were 2-dimensional Gaussian patches (σ = 0.5, 0.25, 0.12, and 0.06 deg) corresponding in size to the 4 lower spatial frequency

Gabors (0.5—4.0 c/deg) used in the previous experiments. These stimuli were unipolar without contrast reversals. Figure 3 shows the data from one subject. With these unipolar stimuli, detection thresholds were reduced as speed increased for all spatial frequencies, similar to what we saw in the parallel conditions of the previous experiments (Figs. 1a and 2a). We did not see effcts of aliasing (Fig 1b) at the higher speeds, probably because of the overall increase in contrast sensitivity.

Figure 3. The sensitivity to a Gaussian, uni-polar patch is similar to the higher sensitiv-ity seen in the parallel condi-tion, verifying that the unipolar characteristic of the stimuli allow for the higher sensitivity.



Experiment 3: The Effects of Tracking on Contrast Thresholds

Although the subject always knew the direction, speed, location, and starting time of the stimuli in the previous experiments, the ability to effectively track the target diminished with target contrast. In order to determine if the reduced sensitivity found when the Gabor targets moved was due to the inability to track the low contrast stimuli, we replicated the experiment described in the Introduction with the following variations. Gabors with spatial frequencies of 1, 2, and 4 c/deg, oriented vertically, were presented for detection. The velocities tested were selected to provide a temporal frequency of 60 c/sec, where sensitivity was lowest (Fig. 1c). On half the trials (randomly selected) a 0.6 ∞ 1.1 deg full contrast rectangular target was presented 3.6 deg above the Gabor. The subject fixated the location of the Gabor on all trials; when the rectangle was present it facilitated tracking by providing a peripheral tracking cue. Figure 4 shows the data from the tracking and no tracking conditions. Sensitivity increased substantially when the tracking stimulus was present, and reached levels similar to stationary gratings of the same spatial frequencies (see data for stationary Gabors in Fig 1b). On the basis of these data we conclude that the dramatic drop in sensitivity we saw in our initial experiment was due primarily to retinal slip.

Experiment 4: Contrast Sensitivity for Moving Wide-band Stimuli

We found that sensitivity as a function of temporal frequency is similar regardless of spatial frequency, but is spatial frequency dependent when analyzed in terms of the velocity of the stimulus. Most video images are wide-band in nature, and some of the spatial frequency components of such wide-band stimuli should be more visible at a given velocity due to aliasing. If such components are superthreshold, they should increase the visibility of the stimulus. To determine whether wide-band stimuli can be detected at lower contrast, in addition to the Gabor patches used in prior experiments, we presented subjects with square-wave patterns embedded in Gaussian envelopes so that the transition point of the square-wave coincided with the peak of the Gaussian envelop. All conditions were randomly interleaved.

The data in Fig. 5 indicate that some of the spatial frequency components of the wide-band (square-wave) stimuli were sufficiently visible to aid detection at velocities at which band-limited (first harmonic) stimuli were less visible. However, sensitivity did not reach the same levels as those we found in Exp. 3 where a high contrast tracking stimulus allowed easy and accurate tracking.

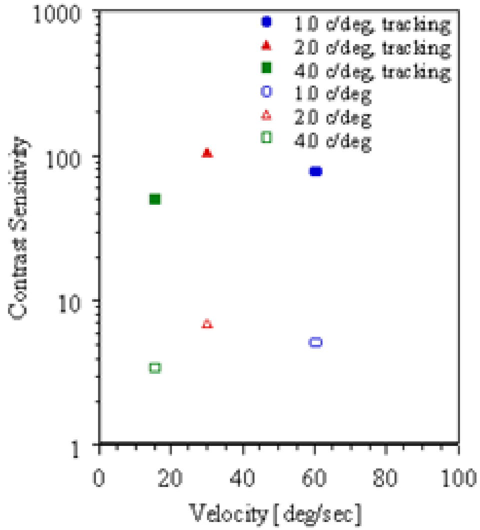


Figure 4. Sensitivity for detection of a target moving together with a high contrast proximal target is increased by about 1 log unit.

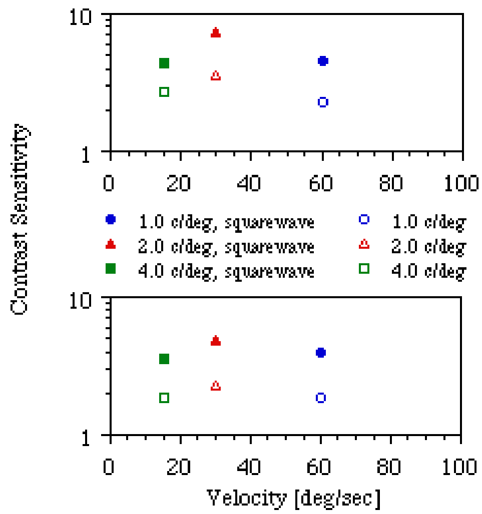


Figure 5. Sensitivity for detec-tion of wide-band stimuli (filled sym-bols) is higher than for band-limited (open symbols) stimuli (data from 2 subjects).

Discussion

The data reported here replicate and extend our previous finding that the visibility of band-limited, oriented, moving features is substantially reduced when the direction of motion is orthogonal to the orientation of the (bipolar) features. When the direction of motion is parallel to the orientation of the features visibility is reduced much less. The decrease in visibility for the orthogonally-oriented features was primarily a function of temporal, not spatial, frequency. The decrease in sensitivity with increased temporal frequency was not due to the sampling rate of the display and would likely occur for any continuously moving stimuli. We also showed that sensitivity increased for unipolar (Gaussian) and wide-band (square-wave) stimuli and when the subject was provided with an external tracking stimulus. Since most moving targets have features in many orientations, the features parallel to the direction of motion may be detected and tracked, thereby increasing the visibility of the whole target.

When the eyes track a smoothly moving target, however, the rest of the scene sweeps across the retina. Our results suggest that the visibility of all but the fixated target in such a scene would be greatly reduced. This reduced sensitivity may help to maintain fixation on a given target without disruption from other objects in the periphery.

In a sampled display, wide-band stimuli may have an advantage over band-limited stimuli due to aliasing. The aliasing of higher-frequency components of the wide-band stimulus increases the visibility of the target and may provide a tracking cue, further increasing the visibility of the other spatial frequencies of the target. As we showed here, tracking a stimulus increases its visibility almost to the level of a stationary target. This finding could have important implications for the enhancement of video displays, where the bandwidth of the image is often modified. High-pass or band-pass filtering is frequently used to enhance images and has been shown to increase the visibility of details in static images. However, given the current findings, these improvements for static images cannot be presumed to carry over to moving displays.

We (Peli et al., 1994) used band-pass filtering to enhance the visibility of images for the visually impaired. On the basis of the data reported here, we have designed a new wide-band enhancement method which expands the bandwidth of the image and the relevant image details, rather than reducing it as with band-pass filtering (Peli, 1997). Such images, in which the important visual features such as edges and bars (Morrone & Burr, 1988) are delineated by sharp, high contrast lines of the appropriate polarity, may be more visible in a moving display than either the original or band-pass filtered versions of the image.

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