Motion adaptation from surrounding stimuli

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stimulus in figure 1b. During the test phase of the experiment, the rest of the screen besides the test strip was uniform at mean luminance. The test gratings were of the same spatial frequency as the adapting grating and were presented for 1 s drifting to the left or to the right at the same velocity as used for the adapting field. In this experiment, the spatial frequency of all adapting and test gratings was 0.4 cycle $\deg^{-1}$, and gratings were drifted at 5, 18, and 30 cycles s^{-1}.

2.2.2 *Induction.* The inducing gratings used to measure the amplitude of induction within the uniform gap were identical to the interrupted adapting stimulus described above (figure 1d). A real grating of adjustable amplitude similar to that shown in figure 1e was added to the uniform central gap of the interrupted adapting stimulus and was used as a nulling grating (figure 1f). The nulling grating had the same spatial frequency, phase, and velocity as the inducing grating. The inducing gratings had a spatial frequency of 0.4 cycle $\deg^{-1}$ and were drifted at constant velocities of 0, 1, 2, 4, 5, 8, 10, 12, 18, and 30 cycles s^{-1} for observers WLS, and at 0, 5, 18, and 30 cycles s^{-1} for observer LB. Mean luminance for all experiments was an equal energy white of 50 cd m^{-2}.

2.3 *Observers*

Observer LB was a naive subject with no prior experience with psychophysical experiments, and was given three hours of training before data were collected. Observer WLS was one of the authors, and had extensive experience with psychophysical experiments.

2.4 *Procedure*

2.4.1 *Adaptation.* In the adaptation experiments, the effect of prolonged viewing of the adapting grating as it moved in one direction was estimated by measuring the change in contrast thresholds for moving gratings. Thresholds were determined by means of an interleaved double random staircase tracking the 80% detection point. Six transitions were run for each staircase, so that each threshold was the mean of twelve values. After initially measuring the contrast thresholds for rightward and leftward motion of the test strip, the adapting pattern was presented for 10 min, drifting to the left. Following adaptation, test thresholds were remeasured with top-up adaptation for 5 s after each trial lasting 1 s. All adaptation experiments described in this paper followed the same procedure.

2.4.2 *Induction.* In the induction experiments, the initial amount of real modulation in the nulling grating was set randomly in each trial, giving no clue as to its amount except for the perceived modulation of the narrow test region. Observers used buttons to control the amplitude of the real grating so as to make the narrow test region look uniform. The average of twenty to sixty such null settings was then taken as a measure of the amount of induction. In the conditions where the inducing and nulling gratings were drifted, the observer was instructed to fixate the center of the screen and not to track the moving grating. This method of measuring induction has the following advantages: the observer looks at the test field at all times, so that the portion of the retina that receives the induced modulation is never exposed to the inducing field, which keeps successive contrast effects to a minimum; this is a null method in that the observer is required to select conditions in which there is no apparent modulation of the critical part of the field, so that the observer does not have to remember a reference field; and finally, the luminance averaged over a cycle of modulation is the same for the whole display, so that the steady-state adaptation is constant throughout the experiments.

2.5 *Results*

2.5.1 *Adaptation.* The results of adapting to motion at different velocities are shown in figure 2. Two indices of desensitization were calculated in order to examine the effect of prolonged exposure to motion on contrast thresholds of moving patterns. The first index reflects the total desensitization, D_t, in the direction of the adapting stimulus and is calculated as the log of the ratio of the postadaptation threshold $T_{\text{post, s}}$ to the preadaptation threshold $T_{\text{pre, s}}$ for test strips moving in the same direction as the adapting stimulus (Sekuler et al 1968; Tolhurst 1973):

$$D_t = \log \frac{T_{\text{post, s}}}{T_{\text{pre, s}}} .$$

Positive values of this index indicate threshold elevations. In figures 2a and b, this index is plotted for each drift velocity for the interrupted (open triangles) and continuous (filled triangles) adapting-stimulus. Results for two observers are shown. The second index reflects directional desensitization, D_d, and is calculated as the log of the ratio of the postadaptation threshold for test strips moving in the same direction as the adapting stimulus, $T_{\text{post, s}}$, to the postadaptation threshold for test strips moving in the opposite direction, $T_{\text{post, o}}$ (Pantle et al 1978):

$$D_d = \log \frac{T_{\text{post, s}}}{T_{\text{post, o}}} .$$

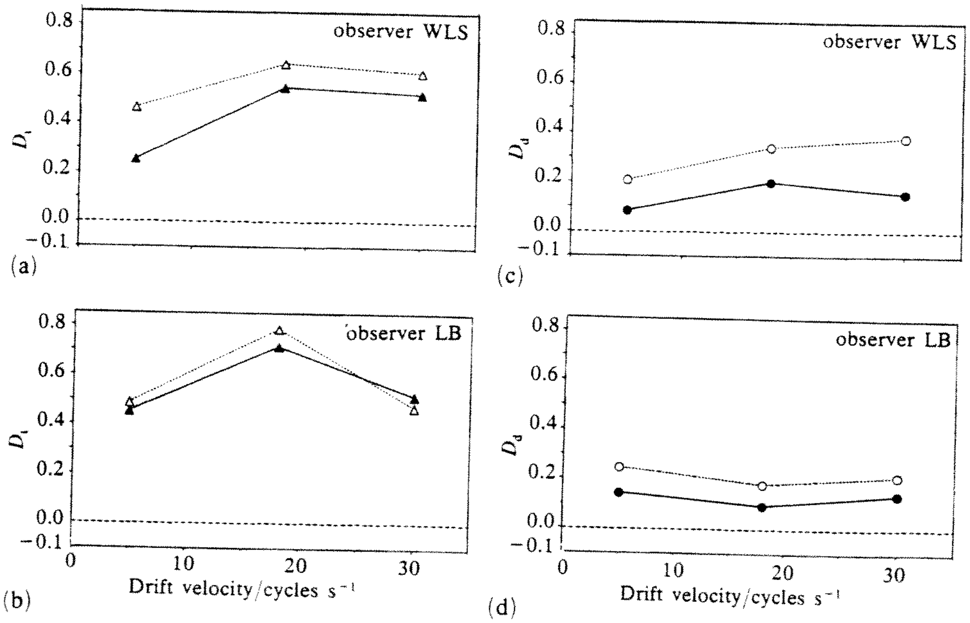

Figure 2. Motion adaptation for a test grating 0.25 deg high, with an interrupted adapting grating (open symbols) or a continuous grating (filled symbols) for different drift velocities. Results are shown for two observers. The gap in the interrupted grating was 0.25 deg high and coincided with the vertical extent of the test strip. The total desensitization index, D_t, (a and b) is the log of the ratio of the postadaptation contrast threshold to the preadaptation threshold for test strips moving in the same direction as the adapting stimulus. The directional desensitization index, D_d, (c and d) is the log of the ratio of the postadaptation threshold for test strips moving in the same direction as the adapting stimulus to the postadaptation threshold for test strips moving in the direction opposite to the adapting direction. Test and adapting gratings had a spatial frequency of 0.4 cycle deg^{-1}. Test strips were drifted at the same velocity as the corresponding adapting stimuli. Data points are connected by straight lines for clarity.

This index is plotted as open and filled circles in figures 2c and d. Positive values of this index correspond to greater desensitization in the direction of adaptation than in the opposite direction.

The open triangles in figures 2a and b always fall above 0.0, indicating that thresholds for moving stimuli were elevated in parts of the retina not covered by the adapting stimulus. Also, the open circles in figures 2c and d show that thresholds were elevated more for the direction of adaptation than for the opposite direction. A comparison of open and closed symbols in figures 2c and d shows that directional desensitization was no less pronounced for the interrupted than for the continuous gratings. Therefore, it is unlikely that the adapting effect of the surround was due to light scattered into the gap from the surrounding stimuli, or to small vertical eye-movements that would expose the retinal subtense of the test to the adapting surround.

2.5.2 *Induction.* The measured decrease in nulling contrast as the velocity was increased correlated well with the phenomenal experience. A comparison of figures 2 and 3 shows that an increase in the drift velocity of the surround had opposite effects on the magnitudes of adaptation and of induction measured within the gap. There was significant motion adaptation in conditions with no measurable grating induction, making it unlikely that motion adaptation in the uniform gap was due to the induced gratings.

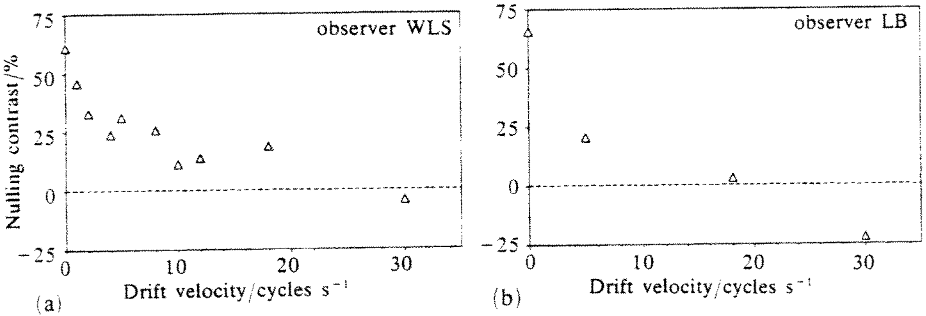

Figure 3. Nulling contrast for a moving grating induced into a uniform field, 0.25 deg high, surrounded by a moving grating, 0.4 cycle deg^{-1}, of 95% contrast, as a function of drift velocity. The vertical axis shows the amount of contrast of a real grating needed to null the induced percept in the test strip, as a percentage of contrast of the inducing grating. For observer WLS, each point is the mean of at least twenty nulling trials. For observer LB, each point is the mean of at least sixty nulling trials.

3 Experiment 2

In the second experiment we compared the adapting and inducing effects of surrounding gratings of different spatial frequencies.

3.1 *Stimuli*

3.1.1 *Adaptation.* The adapting stimuli were continuous and interrupted gratings similar to those shown in figures 1a and b, with spatial frequencies of 0.4, 1.0, and 4.0 cycles deg^{-1}. The narrow strip of test grating always had the same spatial frequency as the adapting grating. The height of the gap and of the test field was 0.25 deg.

3.1.2 *Induction.* The inducing stimuli were interrupted gratings similar to figure 1d with spatial frequencies of 0.4, 1.0, and 4.0 cycles deg^{-1}. The nulling stimuli had the same phase and frequency as the inducing gratings (figures 1e and f). All stimuli were drifted at a constant velocity of 5 cycles s^{-1}.

3.2 *Procedure*

The procedures for measuring adaptation and induction were identical to those used in experiment 1.

3.3 *Results*

3.3.1 *Adaptation.* Total desensitization index is plotted in figures 4a and b and the directional desensitization index is plotted in figures 4c and d. The amount of desensitization due to the interrupted field decreased as the spatial frequency of the adapting and test stimuli increased. The desensitizing effect of continuous gratings as a function of spatial frequency (closed symbols) was very different from that of interrupted gratings (open symbols). For observer WLS, continuous gratings of 1.0 and 4.0 cycles $\deg^{-1}$ elevated thresholds more than did interrupted gratings, whereas for gratings of 0.4 cycle $\deg^{-1}$, interrupted gratings raised thresholds more than the continuous ones. For gratings of 0.4 and 4.0 cycles $\deg^{-1}$, the effects of adaptation for observer LB were qualitatively similar to those for observer WLS.

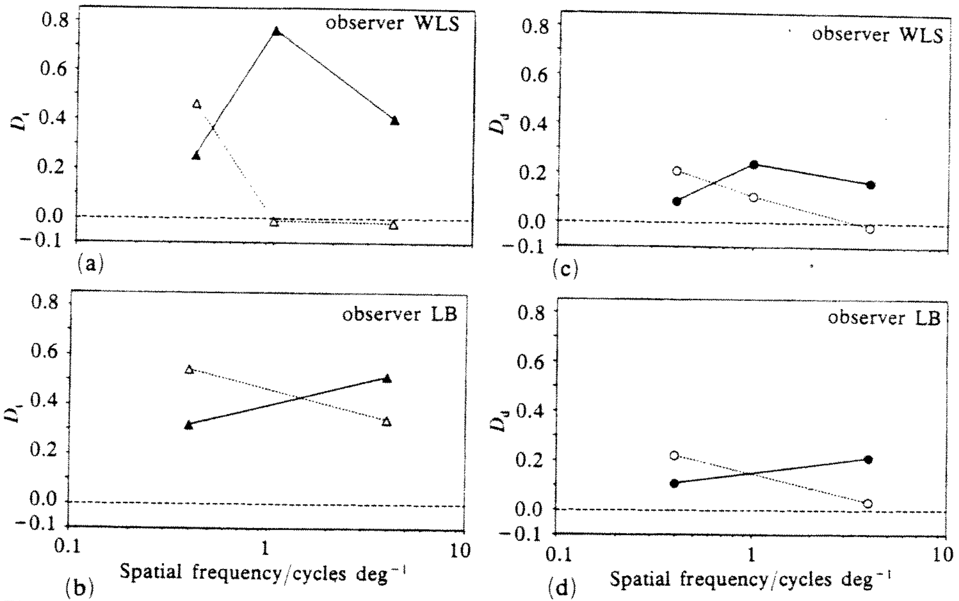

Figure 4. Motion adaptation with interrupted (open symbols) and continuous (filled symbols) gratings of various spatial frequencies. Test strips were of the same spatial frequency as the adapting fields. All gratings were drifted at 5 cycles s^{-1}. Results are shown for two observers.

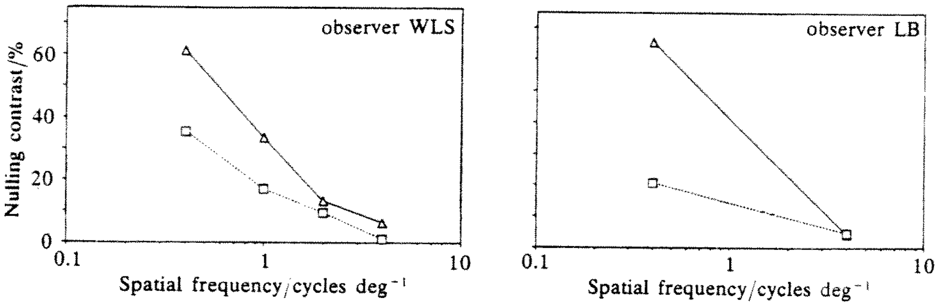

Figure 5. Nulling contrast for stationary induced gratings (open triangles) and for gratings moving at 5 cycles s^{-1} (open squares) within a uniform field, 0.25 deg high, as a function of spatial frequency. For observer WLS, each point is the mean of a hundred null settings for gratings moving at 5 cycles s^{-1}, and of forty null settings for stationary gratings. For observer LB, each point is the mean of eighty null settings.

3.3.2 *Induction.* In figure 5, the open squares show the amount of nulling contrast when inducing gratings at various spatial frequencies were drifted at 5 cycles s^{-1}. There was a monontonic decrease in the amount of nulling contrast required as the spatial frequency was increased from 0.4 to 4.0 cycles deg^{-1}. For comparison, the nulling contrast needed for stationary-grating induction is shown as open triangles. The results for stationary gratings were qualitatively similar to earlier results (McCourt 1982; Zaidi 1989). At a velocity of 5 cycles s^{-1}, adaptation by an interrupted grating and induction by that same stimulus both showed a decrease at the higher spatial frequencies.

4 Experiment 3

Given that adaptation to motion can be reliably measured in retinal areas not exposed to the adapting stimulus, we were curious to see how far from the adapting stimulus the effect could be measured. To measure the spatial extent of motion adaptation, we measured preadaptation and postadaptation thresholds for test strips, 0.25 deg high, centered within gaps of various sizes in interrupted adapting gratings. To test further the effect of induced gratings on the threshold changes, we compared the desensitizing effects of adapting stimuli like figure 1b with those of stimuli like figure 1c. The adapting stimuli in figures 1b and c consist of gratings of the same spatial frequency, orientation, and amplitude, but the gratings in the top and bottom half of figure 1c are offset by a half cycle. The size of the gap in the gratings in figure 1 is not true to scale. At the scale used in the experiments, the induced percept in the uniform central gap in figure 1b was of a vertical grating, but in figure 1c it consists of light and dark patches (Zaidi 1989).

For larger gap sizes the appearance of an induced grating gave way to local induced patches at the edges of the gap. Since the appearance of the test region was not uniform in the vertical direction, the induced percept could not be satisfactorily nulled by a nulling grating of uniform contrast. Therefore, measurements of induced contrast by the stimuli in this experiment were not made.

4.1 *Stimuli and procedure*

The test stimulus was a horizontal strip, 0.25 deg high, of a 0.4 cycle deg^{-1} grating similar to the one used in experiment 1. Contrast thresholds for rightward and leftward movement at 5 cycles s^{-1} were measured before and after adaptation with interrupted gratings. Adapting stimuli were 9 deg × 10 deg fields of 0.4 cycle deg^{-1} gratings moving leftward at 5 cycles s^{-1}. The uniform gap separating the top and bottom half of the real grating was placed in the center of the screen. The two halves of the grating were aligned in one set of conditions, and offset by half a cycle from each other in the other set. The aligned and offset conditions both used central uniform gaps of different heights: 0.25 deg, 0.5 deg, 1.0 deg, 2.0 deg, and 4.0 deg. When the uniform gap was wider, the percept of a cohesive grating in the aligned condition was weaker. At the larger separations, the percept consisted of induced patches at the edges that extended for some distance towards the center of the uniform gap. In the offset condition, the induced checkerboard pattern was similarly drawn out to become local edge patches as the uniform gap increased in width. The experiment thus consisted of testing direction-selective contrast-threshold elevation for a grating, 0.25 deg high, within the region exposed to uniform fields of various sizes and enclosed by horizontal strips of vertical gratings. For observer WLS, the different adapting stimuli consisted of a grating 9 deg high, into which uniform gaps of varying height were inserted. For large gaps, the area of the inducing grating was therefore decreased. For observer LB, the adapting stimuli consisted of two horizontal strips of vertical grating each 2.5 deg high, which were separated by uniform fields of different heights. In this way, the total area of the surrounding grating remained constant for varying gap heights.

4.2 *Results*

In figures 6a and b, the total desensitization index for the test grating is plotted for aligned adapting-gratings (large triangles) and offset adapting-gratings (small triangles). There were no systematic differences betwen aligned and offset adapting-gratings. For both aligned and offset adapting-gratings, total desensitization was maximum at a separation of 0.25 deg and decreased monotonically for larger gaps, falling to zero at a separation of 4.0 deg. Figures 6c and d show the directional desensitization index for the same experiment. Directional desensitization also decreased as the height of the gap increased. Desensitization indices for aligned and offset gratings were similar throughout the range of separations studied.

These results show that the desensitizing effect of offset surrounds was roughly equal to that of aligned surrounds. Therefore, the induced percept of cohesive gratings, for aligned surrounding gratings, did not have a greater desensitization effect on test thresholds than did induced local patches. For both types of surround, the desensitizing effect was highest close to the edges of the adapting stimulus, and gradually decreased with distance from the edge. Almost no threshold elevation was measurable when the gap was 4.0 deg high, ie when the distance between the edges of the adapting and test stimuli was close to 2.0 deg.

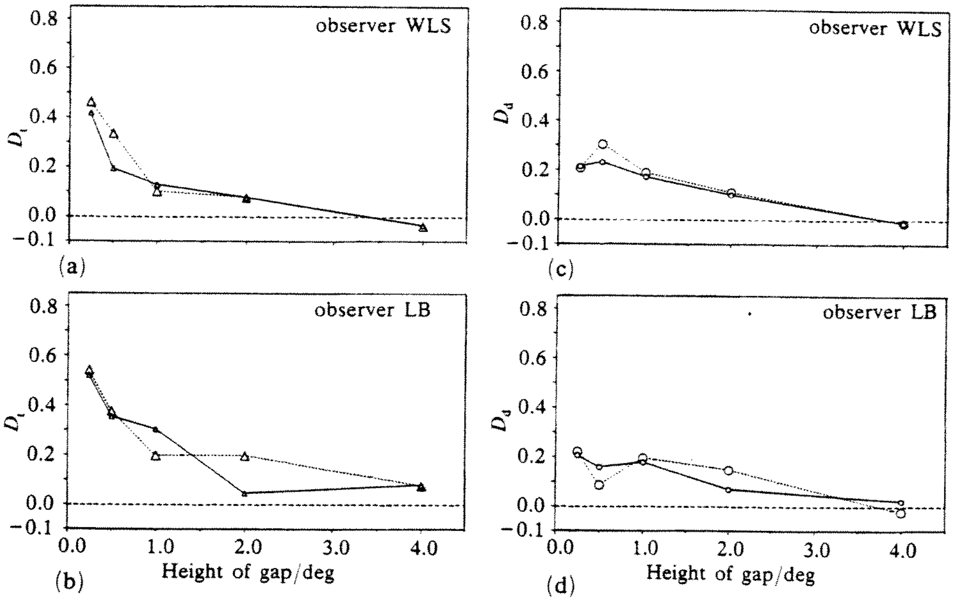

Figure 6. Total desensitization index (a and b) and directional desensitization index (c and d) for motion adaptation within uniform fields of varying height, surrounded by gratings of 0.4 cycle deg^{-1} drifting at 5 cycles s^{-1}. The test field was 0.25 deg high, and was centered within the gap. Adapting gratings were either aligned (large symbols) or offset by half a cycle (small symbols).

5 Summary and discussion

The results in this paper are relevant to two issues: (i) the visual effects of induced percepts, and (ii) the nature of motion-sensitive mechanisms.

A number of investigators have tried to measure the relation between induced percepts and visual thresholds. Cornsweet and Teller (1965) and Sternheim (1970) claimed that the change in appearance of a test due to surrounding fields did not have an effect on increment thresholds if the effects of stray light were taken into account.

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