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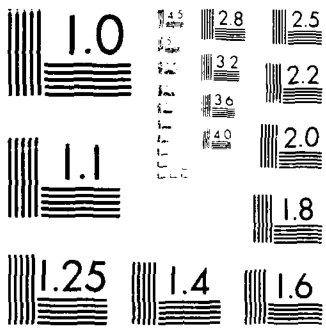
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Numerous experimental observations support the principal investigator's conjecture that human visual segmentation of figure and ground is partly determined by properties of the visual scene. Support dervies from observations that: figure and ground occupy different perceptual depth planes; perceived differences of depth are necessary for figure-ground segmentation; patches of an image are assigned to depth planes partly on the basis of their relative spatial frequency content, temporal frequency content (distinguished from perceived velocity), and retinal disparity. Details of these and other experiments are included with discussion and references.

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FINAL SCIENTIFIC REPORT

Grant AFOSR-84-0115

The Interaction of Sensory and Perceptual variables:
Spatial, Temporal, and Orientation Response to
Figure and Ground

Dr. Naomi Weisstein, Principal Investigator

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FINAL SCIENTIFIC REPORT

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Dr. Naomi Weisstein, Principal Investigator

FINAL SCIENTIFIC REPORT

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Title : The Interaction of sensory and perceptual variables: spatial, temporal, and orientation response to figure and ground

Time period : June 1, 1984 to August 31, 1987

Principal Investigator : Dr. Naomi Weisstein

Post-doctoral research associates : Dr. Victor Klymenko
Dr. James M. Brown

Consultant : Dr. Eva Wong

PART 1 : TECHNICAL REPORT

A large number of digital image processing programs were developed on our Grinnell Image Processing System in order to facilitate the research outlined in the grant. We have the capability of instituting most of the standard image processing techniques such as luminance histogram analysis, luminance and contrast modification, high and low pass filtering etc. We also developed the software capable of doing the following to images or parts of images : selectively inducing various degrees of blur, inducing different degrees of binocular disparity with the anaglyphic method, interactively controlling the disparity in images in real time, adding selected portions of different images together, interactively controlling the contrast of an image in real time, flickering selected portions of images at different temporal frequencies.

During the first year of the grant we had several technical problems which were solved by equipment replacement. The Winchester Drive on the computer hosting the Grinnel crashed severely enough to warrant the purchase of a CDC drive as replacement. The Grinnell also had some power supply problems that were corrected. The GT-40 system had been most reliable until this past year. A problem with ghost images in the monitor screen has been attributed to an unknown system problem emanating from within the PDP 11/34. The 11/34 was an upgrade from the 11/05 neceesitated by the failure of the Plessy memory boards associated with the 11/05. An RX01 floppy drive has been added to this system allowing communication between the 11/23 (the Grinnell host) and the 11/34 (the GT-40 host).

<u>PART 2 : SCIENTIFIC PROGRESS REPORT</u>

The initial three years on this research project have been highly successful. Our pre-proposal findings had shown that sharp line segments are detected and discriminated better in figure regions, while blurred line segments are detected but not discriminated better in those same regions when seen as ground. Also, we had some data showing that identification/detection ratios were larger for targets 1.6 degrees apart in orientation when these targets were seen against figure versus ground regions. Finally, we had preliminary data showing that flickering regions were predominantly perceived as ground behind nonflickering regions which were perceived as figure.

On the basis of these data and on our organizaing hypothesis discussed in this report, that figure perception involves high spatial frequency, slow analysis of details while ground involves the fast processing of low spatial frequency, more global aspects of an image, we made the following predictions:

1) Contrast sensitivities for sinewave gratings imaged in backgrounds would be greater at low spatial frequencies; those for sinewave gratings imaged in figure would be greater at high spatial frequencies.
2) The orientation bandwidths for tilted targets would be narrower in figure than in ground regions.
3) The time-course of visual signals would be faster from ground than from figure regions.
4) High spatial-frequency-filled regions would appear as <u>figure</u> in relation to low spatial-frequency-filled regions, which would appear as <u>ground</u>.
5) High temporal-frequency-regions would appear as <u>backgrounds</u> in relation to low temporal-frequency-filled regions which would appear as <u>figure</u>.
6) Regions moving at high velocities would appear as <u>backgrounds</u> in relation to non-moving or slow-moving regions which would appear as <u>figure</u>.

Qualitatively, our findings corroborated these predictions. However, our findings have provided some interesting amplifications on our organizaing hypothesis. First, spatial frequencies may be coded relatively rather than absolutely in figure-ground perception. Second, although the data are still unclear, it appears that both relative and absolute flicker frequencies are used in determining figure-ground perception. Third, our findings suggest that temporal frequency may be a more powerful cue to figure and ground than spatial frequency. Fourth, some preliminary findings on the effects of perceived velocity on figure-ground perception suggest that velocity and temporal frequency have different effects on the perception of figure and ground. Fifth, perceived depth accompanying the spatially and temporally induced figure-ground effects is crucial in maintaining the perception that a region is figure or ground. Sixth, images filled with regions of different spatial or temporal frequency yield multi-stable percepts. Regions filled with higher spatial or lower temporal frequencies are perceived <u>more often</u> as figure than background, but they are perceived as background some of the time. Interestingly, binocular disparities also yield multi-stable percepts with our displays. This suggests that instability of figure and ground may be common when only one or another determinant of these perceptions operating. That is, the question we should be asking of all figure-ghround perceptions is "why are they <u>stable</u>?" rather than "why are such and such isolated configurations <u>unstable</u>?"

Our findings are summarized below. Also summarized at the end of the report are studies of other visual phenomena that we have been working on. Reprints and preprints of work performed during the granting years are included in an appendix.

<u>A. The effects of figure-ground perception on the spatial, temporal, and, orientation response of the visual system</u>

1. The contrast sensitivity response in figure versus ground (Wong and Weisstein, 1987)

Having found evidence that the spatial frequency response (thresholds for sharp versus blurred lines) differs in figure versus ground regions (Wong and Weisstein, 1983) we investigated precisely how this spatial response differed. We studied the contrast sensitivity response in figure and ground regions. The figure-ground context was the Rubin faces-vase ambiguous picture (Figure 1) covering an area of 6.4 by 6.4 degrees.

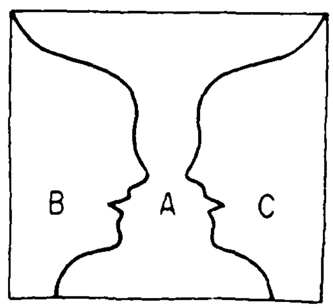


Figure 1 · The Rubin faces-vase ambiguous picture. The sinewave grating patch was presented in the middle of the picture at the location of the fixation stimulus.

The target was a spatially and temporally Gaussian-modulated sinewave patch 1.75 by 1.75 degrees and was presented at the fixation point in the middle of the picture. The mean luminance of the grating and the luminance of the background was 20 cd/m2. The observer's task was to adjust the contrast of the grating until it was just visible. The spatial frequency of the target ranged from .5 cpd to 16 cpd in half octave steps. In one block of trials, the observer made the adjustment only when the central region was perceived as figure; in another block of trials, the observer made the contrast adjustment only when the central region was perceived as ground. (We did not present the target peripherally as we have already established that eye movements were negligible under our fixation conditions and did not account for our effects [Wong and Weisstein 1982, 1983; see also our metacontrast studies below.] However, for thoroughness, we propose some peripheral target conditions in the continuation request.) We found what we predicted: The sensitivities for gratings imaged in a figure region were shifted toward the higher spatial frequencies while those for gratings imaged in a ground region were shifted to the lower spatial frequencies. Figure 2a and 2b show the CSF from two observers.

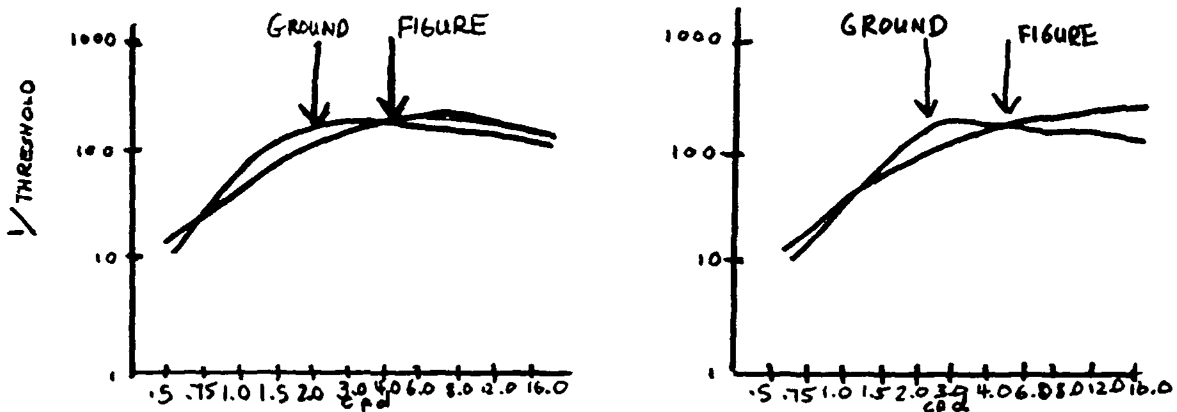


Figure 2a, 2b : The contrast sensitivity response in figure and ground regions. Data are from two observers. Each data point is based on the mean of ten adjustments.

The functions we obtained, however, did not have very prominent peaks, and there was a good deal of response variability. One of the reasons why we were unable to obtain more definitive CSFs might be our psychophysical method. We used the method of adjustment in which the observer adjusted the contrast of the grating until it was visible. Under this condition it might be difficult for the observer to make the adjustment while monitoring which region was perceived as figure or ground. Moreover, the alternating perceptions of a region as figure or ground may fluctuate too rapidly for the adjustment to be made within the period of time a region was seen totally as figure or as ground. These problems prompt us to re-run the study using the temporal two-alternative forced-choice method in obtaining the contrast response. This method has the advantage of constraining the response to within the time period that a region is perceived as figure or ground. It also reduces demands on the observer by simplifying the task (see section D, Methods of Procedure, in the renewal request).

2. The orientation response to figure and ground (Weisstein and Wong, 1986)

Our organizing hypothesis predicts that resolution of details such as discrimination of the orientation of tilted lines will be enhanced in figure regions. Early findings (Weisstein and Wong, 1986) suggested that the facilitative effects of figure on orientation discrimination might be due to narrowing of orientation bandwidths in figure regions. Preliminary data showed that targets 1.6 degrees apart in orientation are detected and discriminated equally well in figure regions but detection is markedly better than discrimination for the same pair of targets presented in ground. Using the assumptions and methods of the identification/detection ratio (Thomas and Gille, 1979; also see below) we examined the identification/detection ratios of targets whose orientations differed by 3.2, 4.9, 9.8, 13.0, 19.5, 25.8, and 31.8 degrees. The temporal two-alternative forced choice method was used to collect data. Each orientation difference yieldeded discrimination thresholds at .5, .6, .7, and .8 detection thresholds. From this we estimated a slope (the mean discrimination/detection ratio) for each orientation difference.

Table 1 shows discrimination versus detection of targets presented in figure and ground expressed as identification/detection (I/D) slopes. Slopes which approach unity indicate that the pair of stimuli are at least one bandwidth apart (see below). Here again, our results confirm our hypothesis.

Orientation differences in degrees	Figure	Ground	Line alone
3.2	.51	24	43
4.9	.86	22	.33
9.8	1.0	27	33
13.0	.91	46	54
19.5	98	.46	.79
25.8	.98	78	96
31.8	.95	94	94

* The slopes are calculated from the discrimination/detection ratios.

Table 1 : Identification/detection (I/D) slopes of targets presented alone and in figure and ground contexts for seven orientation differences for two observers.

The table shows that I/D slopes for targets in figure regions asymptote towards unity at 9.8 degrees; those in ground regions approach unity at 31.8 degrees; and those in contextless fields approach unity at 25.9 degrees. The orientation difference at which I/D slopes approach unity reflects the orientation bandwidth of the targets in our stimulus conditions. According to Thomas and Gille (1979) and Thomas, Gille, and Barker (1979), to the extent that one or both of a pair of stimuli affect one or more detectors, the stimuli will be confused, thereby lowering the I/D slope. When discrimination is as good as detection, the I/D slope will approach unity as each target affects separate detectors. Thus our findings indicate that orientation bandwidths narrow for targets perceived in figure regions.

3. The time-course of figure versus ground processing : metacontrast masking studies (Weisstein and Wong, 1986, 1987)

Having made headway into the spatial and orientation response in figure and ground, we turned our attention to the time course of responses in figure and ground regions. Our prediction was that the visual response in figure would be slower than that in ground. We investigated this hypothesis by looking at the time-course of figure-ground effects on tilt discrimination. In this experiment the observer discriminated the tilt of a line segment (45 degrees left or right of vertical) which was flashed for 50 msec. At various times before, after, or simultaneously with the target the Rubin picture was flashed for 50 msec. The target was always presented in the middle of the picture. There were seven stimulus onset asynchronies (SOAs) in which the Rubin picture appeared before the target, seven SOAs in which the Rubin picture appeared after the target, and one condition in which target and Rubin picture context were presented together. The observer's task was to make a forced choice response as to whether the target line was tilted to the left or right, followed by indicating whether, during the flashed presentation of the Rubin picture, a vase or two faces was seen. If a vase was perceived, this constituted a trial in which the target was imaged in a figure region. When faces were perceived, this constituted a trial in which the target was imaged in a ground region. The results are shown in Figure 3.

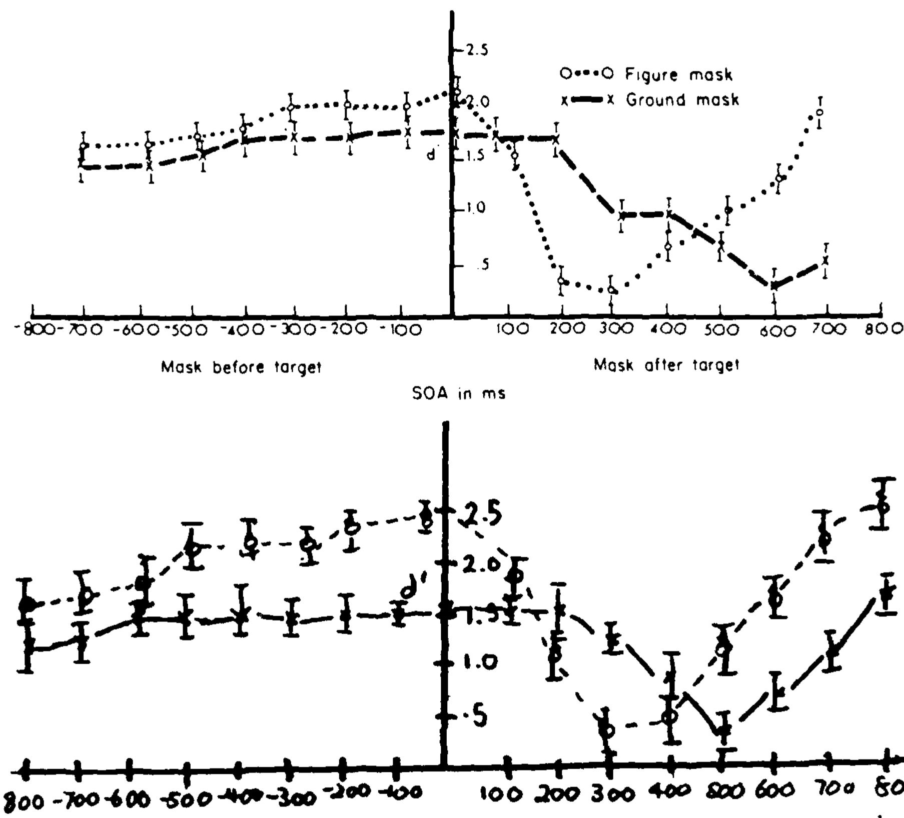


Figure 3 : The time-course of visual response to targets presented in figure versus ground regions revealed by masking. Data are from two observers. Results from one other observers show similar trends.

Under these conditions, we expected to plot the time-course of figure facilitation and ground interference. Wong and Weisstein (1982) showed that figure facilitates target discrimination relative to a target in a contextless filed while ground intereferes with discrimination. We expected that the figure facilitation would precede the ground interference in SOA, since relative to a constant target response, a faster contextual influence could be presented later in time for maximum effect. For SOAs of -300 msec through 0 msec, the tilt discrimination of targets was facilitated by figure, confirming the earlier findings of Wong and Weisstein (1982) and confirming our prediction that figure facilitation would occur at negative SOAs, indicating a relatively slow process. But no corresponding interfering effects of ground were observed. Rather, to our great surprise, at positive SOAs, we found masking by both figure and ground! This masking was backward masking (metacontrast) --- the target appeared before the masking context. No metacontrast masking has previously been reported for the conditions we used -- 30 min separation between target and masking contours, SOAs beyond 200 msec (see Williams and Weisstein, 1981; Breitmeyer, 1984). These metacontrast conditions, however, amply confirmed the hypothesis that ground processing was faster than figure processing. When the masking contour was perceived as the "background boundary" of the region where the target was presented (i.e. when the target was perceived against ground), the SOA yielding maximum masking occurred at about 600 msec. On the other hand, when the masking contour was perceived as the "figure-boundary" of the regions where the target was presented (i.e. when the target was perceived against figure), the optimal masking SOA was between 200 and 300 msec. According to contemporary theories of metacontrast masking (see Breitmeyer, 1984; Weisstein 1972, for an analysis), longer delays between target and mask indicate faster mask processing: it is as if the mask must have a very fast latency or neural conduction time and/or rise-time to "catch up" with the target. As with our detection, discrimination and orientation results, it appears that we are looking at a purely perceptual effect. At an SOA of 200 msec, if one sees the region as figure, masking is obtained; if one sees the region as ground; no masking is obtained. Supporting this is the fact that no metacontrast masking has ever been reported before for these contour-mask conditions (Weisstein, 1972; Breitmeyer, 1984). We shall further examine this perceptual metacontrast masking in several experiments proposed in our continuation grant request.

B. The effects of spatial and temporal frequency responses in the visual system on figure-ground perception

1. The Spatial Response

1.1 Spatial frequency differences can determine figure-ground organization (Klymenko and Weisstein, 1986)

So far we had collected evidence that figure and ground perception differentially influence the spatial and temporal response. Was the converse true? Would the responses of similar spatial and temporal mechanisms be involved in determining which area of the visual field will be perceived as figure versus ground?

We now have overwhelming evidence which supports the conjecture that the spatial frequency response affects the perception of figure and ground. Regions of ambiguous pictures (the Rubin picture, the Maltese Cross, and a bipartite field; see Figure 4) were filled with sinewave gratings of different spatial frequencies ranging from .5 to 8 cpd at one-octave intervals. These stimulus combinations yield spatial frequency differences between regions of the ambiguous pictures ranging from one to four octaves.

Figure 4 : The Maltese Cross ambiguous picture filled with sinewave gratings. The higher spatial frequency filled areas are perceived predominantly as figure and the lower spatial frequency filled areas are perceived predominantly as ground

The combinations of spatial frequencies in different regions in the picture yielded multi-stable perceptions. Figure-ground stability as a function of spatial frequency difference was measured by the percentage of time one of the regions was perceived as figure. It was found that regions filled with the higher spatial frequency were perceived predominantly as figure and regions filled with the lower spatial frequency were perceived predominantly as background. As the octave separation between the regions increased, the percentage of time the higher spatial frequency region was seen as figure increased. These findings reveal that relative rather than absolute spatial frequency values determine whether a region will be perceived as figure or ground. The results are illustrated in Figure 5.

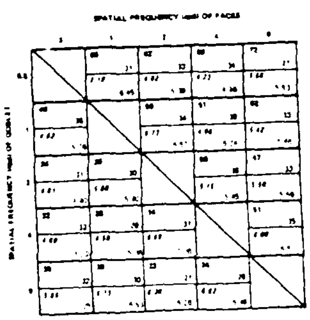
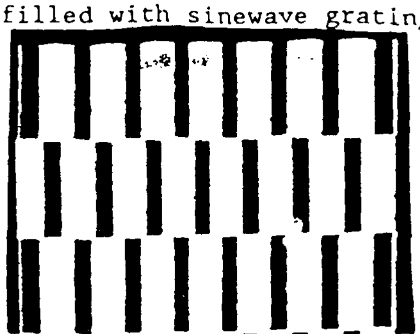


Figure 5 : The percentage of time a region was seen as figure versus ground as a function of the relative spatial frequency between the regions

1.2 A spatial frequency effect on perceived depth (Brown and Weisstein, 1987)

In the previous study, a pronounced depth effect was observed with the perception of figure and ground. Figure was always perceptually localized in front of ground. We next turned our attention to this spatial frequency-induced depth effect (Brown and Weisstein, 1987). We assessed the amount of depth induced by spatial frequency differences by cancelling it with depth induced stereoscopically in the opposite direction. Crossed disparity was added to one or both regions of a pattern containing sinewave gratings differing in spatial frequency. The display consisted of rectangular areas filled with sinewave gratings (see Figure 6a).



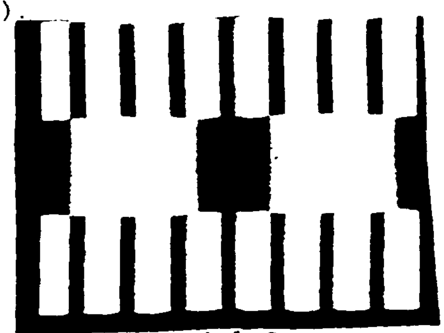


Figure 6a and 6b : Display pattern for investigating spatial frequency effects on perceived depth

We found that the regions with the higher spatial frequency were perceptually localized in front of the lower spatial frequency regions. Again the effect was dependent on the relative spatial frequency difference between the regions. Moreover, when spatial frequency difference between the regions was greater than 1.32 octaves, the higher spatial frequency region tended to be seen as foreground a greater percentage of the time regardless of the disparity imposed on the regions, i.e. spatial frequency difference dominated binocular disparity as a cue to depth. Using the same configuration, we then instructed observers to cancel the depth induced by spatial frequency differences between the regions by adjusting the disparity of the image so that all regions within the display lay on the same depth plane. Here we found that observers consistently placed the relatively lower spatial frequency filled regions closer in stereo depth than the relatively higher spatial frequency filled areas. Similar trends were observed when the gratings were placed out-of-phase. The display is shown in Figure 6b. The findings are presented in Table 2. Finally, the procedure was repeated using square wave gratings. Although depth was occasionally observed, neither region was reliably perceived in front of the other.

		Mean Disparity Setting			
	Phase Relation	Octave Separation in sf			
Experiment	within *I's & II's*	1.32	2.0	3.32	
2	IN	4.8"	102"	43.2"	
3	IN	-1.1"	41.3"	52.8"	
	OUT	7.7"	30.3"	45.8"	
4	IN	-16.2"	-5.6"	-5.6"	
	OUT		-3.9"	2.5"	-20.1"

Table 2: Mean disparity settings when the lower and higher spatial frequency regions appeared in the same depth plane. Positive settings indicate that the relatively lower spatial frequency regions were placed closer in stereo depth

1.3 Spatial frequency, perceived depth, and figure-ground perception (Wong and Weisstein, 1987b)

Thus, we found that spatial frequency differences between the regions of the visual field can be a powerful determinant of whether a region will be seen as figure or ground, and that accompanying the figure-ground perception induced by spatial frequency differences is the visual impression that the segregated areas are localized on different depth planes. We next investigated the joint roles of spatial frequency and perceived depth in the perception of figure and ground by stereoscopically cancelling perceived depth induced by spatial frequency differences. Two displays (the disk-annulus configuration and the diagonal-triangles configuration; see Figure 7a and 7b) were used.

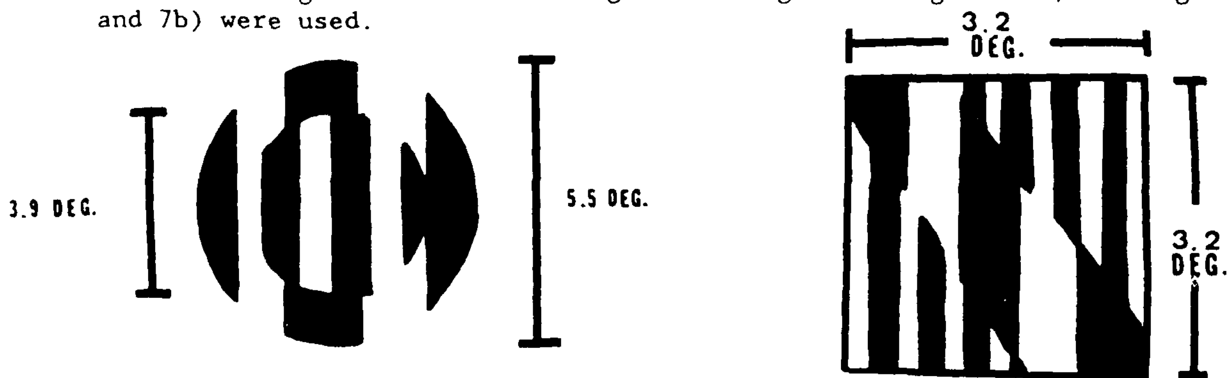


Figure 7a and 7b : The disk-annulus and the diagonal-triangles configuration

As expected, when spatial frequency differences and perceived depth were both present, the lower spatial frequency region was seen predominantly as ground and was localized behind the higher spatial frequency region. However, when no depth was perceived between regions of the ambiguous pictures (depth induced by spatial frequency difference being cancelled by stereoscopic depth in the opposite direction), the effect of spatial frequency differences alone on the dominance of regions as figure and ground diminished substantially although a small residual effect remained. When regions were filled with identical spatial frequencies and perceived depth was induced stereoscopically between the regions in the ambiguous picture, the region perceived farther away was predominantly seen as background. (Note: The finding that the region localized in back was seen as background is not as obvious as it may first appear. When we fixate on, say, a squirrel some distance away, both the grass in front of it and the hills in back of it may be said to be ground.) A summary of these results is presented in Figure 8.

		Perceived Depth: Present (at maximum)	Perceived Depth: Absent
Spatial Frequency Difference	Present (at maximum)	95% GOOD Exp. 1 and 2	66% POOR Exp. 3
	Absent	88% GOOD Exp. 4	55% NONE Exp. 4

Figure 8 : Summary of results showing the joint effects of spatial frequency differences and perceived depth in determining the dominance of figure and ground

<u>Discussion of spatial results</u>

Here we encounter the first amplification of the organizing hypothesis concerning the association between the spatial frequency response and figure-ground perception. What determined whether a region would be perceived as figure or ground depended on the spatial frequency of a particular area <u>relative</u> to the other spatial frequencies in the image. These findings of relative effects of spatial frequency on figure-ground perception are consistent with the point made by many researchers that the perception of the visual world is little affected by changes in scaling (see for example Koenderink and van Doorn, 1982; Burbeck, 1986; Norman and Ehrlich, 1987).

These findings of relative rather than absolute spatial frequency influences may at first glance seem to conflict with the findings presented in Part A above. There we found a high spatial frequency response to figure (sharp targets, rightward shift in the CSF) and a low spatial frequency response to ground (blurred targets, leftward shift in CSF). However, models of relative spatial frequency coding can be readily inferred from our overlapping CSF functions and as we obtain better estimates of these functions we will be able to construct some plausible theories which are compatible with both sets of data. In addtion, differences in picture contexts or grating-patch size (see Methods of Procedure in the continuation request) may produce shifts in the CSFs due to image scaling, and these shifts, too, would enter into our theoretical picture.

Finally, we have seen that perceived depth appears to mediate the perception of figure and ground (and, interestingly, that perceived depth yields a multistable perception in our conditions whether it is generated by spatial frequency differences or by stereoscopic disparities). That depth and figure-ground coding are closely associated has been often noted. We will not propose any specific studies that further explore perceived depth and figure-ground relationships for example, conflicting monocular cues to spatial-frequency induced depth - but we will keep this issue in mind and will always track perceived depth mediation of figure and ground as we investigate further stimulus variables that induce such perceptions.

An interesting sideline to our findings of relative spatial frequency effects in figure-ground perception is that the higher spatial frequency region (thinner bars) was perceived as figure lying in front of the lower spatial frequency region (wider bars). This appears to contradict the common knowledge of size-distance scaling. Although no specific experiments dealing directly with this issue are included in the continuation proposal, we shall keep this in mind when we investigate the scaling effects described above.

2. The Temporal Response

While our predictions relating spatial frequency to figure-ground. perception proceeded from our general organizing hypthesis without initial experimental exploration, our study of the role of the temporal response in figure-ground perception was based on some observations regarding flicker and perceived depth. In a pre-proposal report of preliminary findings, we described a "flicker-induced depth" effect. We observed that flickering regions of a random-dot field tended to be perceptually localized behind nonflickering regions. This phenomenon was investigated more systematically during the funding period. We examined the relations among temporal frequency (as flicker), perceived depth induced by the flicker, and figure-ground perception.

2.1 Flicker-induced depth and related effects (Wong and Weisstein, 1984, 1985)

These effects were described in the preliminary report in the proposal and we shall only mention them briefly here. Flickering a region makes it look as if it were behind a nonflickering region. Observers often report that the flickering regions appeared like backgrounds shimmering behind the static regions. This effect is very robust and can be obtained regardless of the stimulus pattern in the flickering and nonflickering areas. In addition, there was a range of optimal flicker frequencies (6 to 8 Hz) at which maximum depth was observed. The effect diminished as flicker frequencies increased or decreased. The effects were also maximal when the flickering regions were modulated at 100% luminance. However, the flicker-induced depth effect was not attributable to luminance or perceived brightness difference between the flickering and nonflickering regions. Theories of brightness as a cue to depth predict that the brighter region would be perceived nearer than the dimmer region (Ittelson, 1960). However, in our studies, regions which were flickering but brighter than the nonflickering regions were perceptually localized as farther away.

2.2 The effects of flicker on the perception of figure and ground (Wong and Weisstein, 1987a)

In this study we found that flickering regions of an ambiguous picture were perceived predominantly as backgrounds, and adjacent nonflickering regions were perceived predominantly as figures. The displays together with the visual impression they created are shown in Figure 9a and 9b. This was true whether or not the regions were outlined by contours or merely defined by temporal changes. This effect of "flicker-induced ground" was optimal when the flickering frequencies occurred between 6 and 8 Hz. Maximum perceived depth segregation between the flickering and nonflickering regions also occurred at these flicker rates. At lower (1.4 Hz) and higher flicker (12.5 Hz) rates, regions maintained their segregation but the dominance of a region as figure or ground and the depth segregation between the flickering and nonflickering regions diminished. This tuning function of flicker-induced ground appears to be similar to those of visual pathways most sensitive to high temporal frequency. This suggests a close relation between the high temporal frequency response and ground perception. Sample findings are presented in Figure 10.

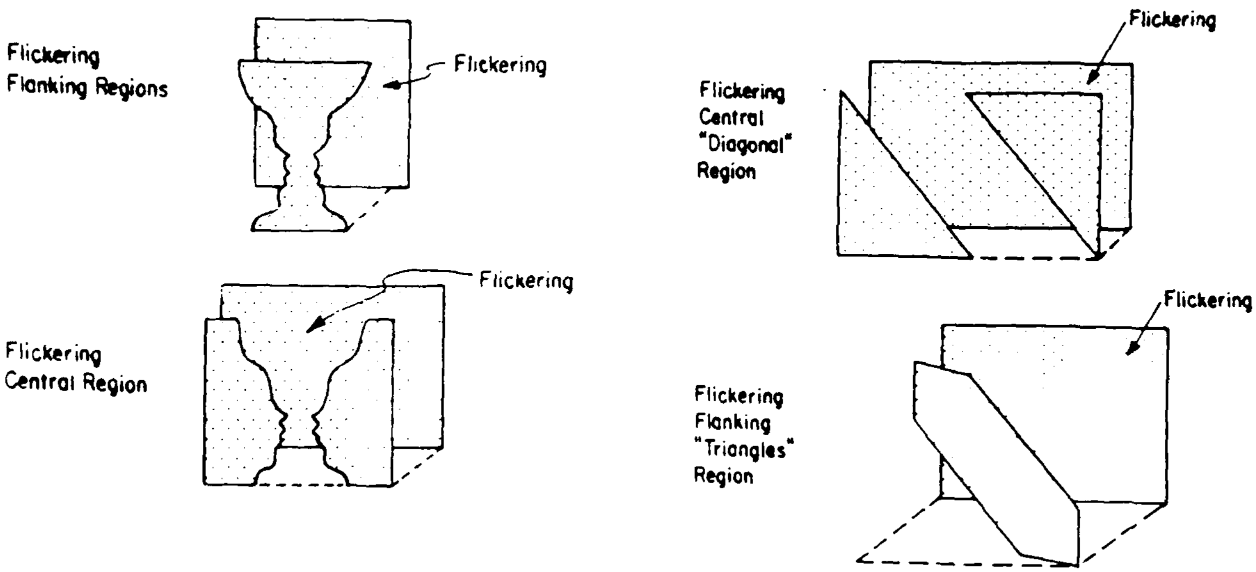


Figure 9a and 9b : Displays used in examining the effect of flicker on figure-ground perception and the visual impression they created

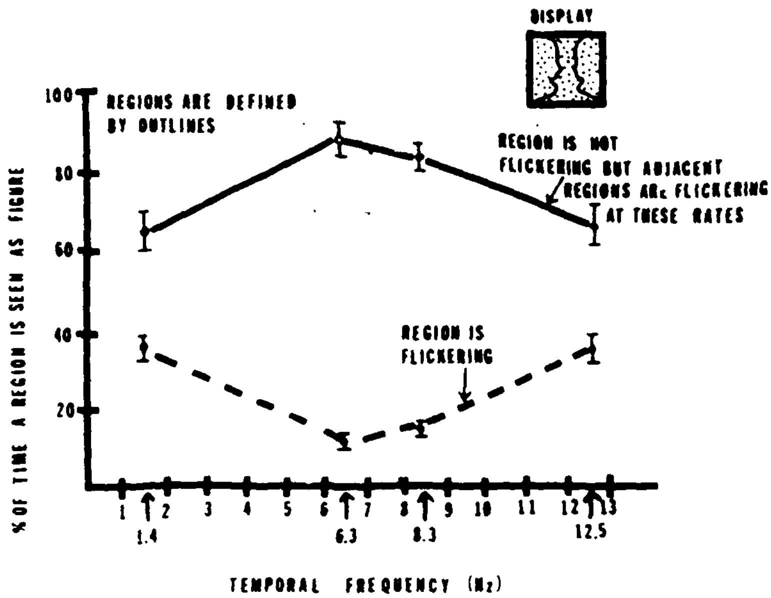


Figure 10 : The percentage of time a region was seen as figure is plotted as a function of temporal frequency. The figure shows the ambiguous picture used

2.3 Flicker, perceived depth, and figure-ground perception (Wong and Weisstein, 1987c)

As with spatial frequency, temporal frequency differences also induce depth. We next examined the joint roles of flicker and perceived depth on the perception of figure and ground by stereoscopically cancelling the depth induced by the flickering region. (This experiment was similar to 1.3 above using temporal rather than spatial frequency). The figure-ground context was the diagonal-triangles picture filled with random dots (see Figure 9b). The percentage of time a flickering region was perceived as ground was measured for four temporal frequencies (1.4, 6.3, 8.3, and 12.5 Hz). Binocular disparity was introduced into the regions and the amount of relative disparity required to cancel perceived depth induced by flicker at each of the flicker frequencies was recorded. We also tested binocular disparity alone, without flicker, as a cue to figure-ground and perceived depth. The percentage of time the flickering regions were perceived as background was obtained when the flickering and nonflickering regions were perceived as coplanar. When flicker was absent we introduced depth stereoscopically and again measured the percentage of time the region localized farther away was seen as background. Results indicate that when perceived depth between regions was absent, the effect of flicker on the perception of a region as ground diminished substantially. When perceived depth (produced stereoscopically) without flicker was present, the region localized in front was predominantly seen as figure and the region localized farther away was predominantly seen as ground. Note that in this condition without flicker but with stereoscopic depth, a mutli-stable perception was also produced. These findings are shown in Figures 11 and 12 respectively.

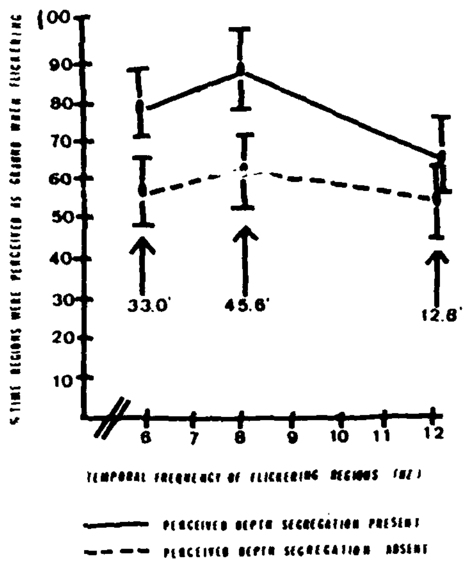


Figure 11: The percentage of time the flickering regions were perceived as background when perceived depth was present versus when perceived depth was absent

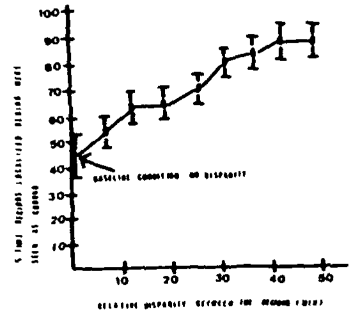


Figure 12 : The percentage of time regions localized farther away was seen as ground as a function of relative disparity

Discussion of temporal results

In general, our hypothesis relating high temporal frequency to ground perception was supported. However, contrary to our results with spatial frequency and figure-ground, flicker-induced ground appeared to have a tuning function, with the peak centered around 6 to 8 Hz. However, given the findings that will be reported below it is premature to conclude that the temporal response in figure-ground perception is absolute rather than relative in nature. In our experiments the flickering regions were always seen in relation to static regions. When regions are flickered at different rates, however, temporal tuning appears to diminish (see below). Furthermore, random-dot displays contain spatial frequencies across a wide range of the frequency spectrum. Thus, in random-dot displays we might be observing the temporal response of a number of spatial frequency-tuned mechanisms together. Finally, we used on-off flicker. Sinusoidal flicker of a single sinewave may yield stull different results. In the next section we report effects of flicker on figure and ground in conditions in which the display contained only one spatial frequency at a time. However, square-wave flicker was still used.

Again, we would like to comment on the fact that these temporal results, like our spatial frequency results, contradict the notion of temporal changes as cues to distance. If flow fields (as in motion parallax) are regarded as cues to distance, viz. that faster moving fields are localized nearer the observer than slower moving fields (Farber and McConkie, 1979; McConkie and Farber, 1979; Rogers and Graham 1982), one would expect that perceived distance should conform to some monotonic relation to the rate of temporal change. However, our findings on the relation between temporal frequency and perceived depth were that perceived depth first increased with flicker rate until 8 Hz and declined again, showing an inverted U-shape function of flicker rates. These findings suggest that the role of temporal change in perceived depth as well as in figure-ground perception is more complex than previously thought.

3. The Spatio-temporal Response

So far we have been investigating the figure-ground response to spatial and temporal frequency by manipulating these variables separately and observing their effects. We have found that relative spatial frequency differences affect which region of the visual field will be seen as figure and which will be seen as ground. We have also found that a temporal tuning frequency of 6 to 8 Hz causes a flickering region to be optimally seen as ground. What about the combined effects of <u>both</u> spatial and temporal variables?

3.1 Spatial and temporal frequency and figure-ground organization (Klymenko, Weisstein, and Topolski, 1987)

First, we asked the question, does flicker induced ground perception change when the uniform spatial frequencies of an image increase? For each of <u>four</u> spatial frequencies, we investigated the effects of relative flicker on the perception of figure and ground. We used the Maltese Cross ambiguous picture (see Figure 13). The diameter of the circular area enclosing the Maltese Cross was 5.66 degrees. The mean luminance of the area occupied by the Maltese Cross pattern was 39.0 cd/m2. The surrounding background was dark (9 cd/m2).

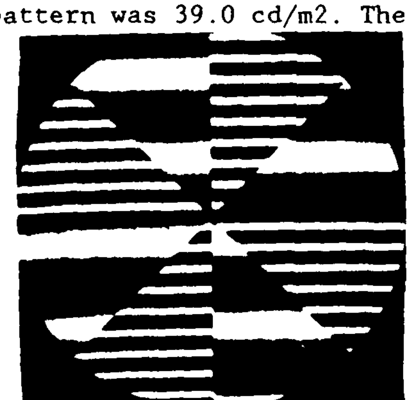


Figure 13 : The Maltese Cross filled with sinewave gratings.

There were four flicker rates (0, 3.75, 7.5, 15 Hz) and four spatial frequencies (0.5, 1, 4, 8 cpd). We used square-wave on-off flicker, in which the grating pattern alternated with a blank field whose luminance equaled the mean luminance of the grating. The observers first matched the flickering gratings (3.75, 7.5, 15 Hz) to a stationary grating at each of the spatial frequencies (.5, 1, 4, 8 cpd). These were the contrast settings for the main experiment in which observers monitored the time in which a particular region of the display was perceived as figure versus background for 30 seconds. The observer moved a joystick right or left to indicate whether the cross oriented left or right of vertical was seen as background. There was also a "null" response, indicated by the "middle" position of the joystick, in which neither cross was perceived as figure. We recorded the mean percent response time observers saw the rightward-tilted cross as the background. The data are shown in Figure 14.

TEMPORAL FREQUENCY (Hz) OF RIGHT CROSS

TEMPORAL FREQUENCY (Hz) OF LEFT CROSS	0		3.75		7.5		15	
0	EXPERIMENT 1		79.0	22 3	77.4	22 2	86.1	23 6
	EXPERIMENT 2		63.6	18 0	60.6	16 9	65.3	18 0
	EXPERIMENT 3		50.9	13 7	82.1	22 8	77.7	22 2
	EXPERIMENT 4		72.9	20 8	59.2	16 8	67.5	18 8
3.75	31.1	8 8	8 cpd		46.8	12 8	63.9	17 7
	26.1	7 4	4 cpd		54.4	14 9	72.6	19 3
	27.0	7 7	1 cpd		66.1	18 6	58.7	15 9
	20.1	5 9	0 5 cpd		60.3	16 9	32.4	9 1
7.5	24.6	7 0	58.9	16 3	HI-TEMFRES		50.7	14 4
	26.4	7 6	47.9	12 2			63.4	17 0
	14.1	4 1	34.9	9 8			62.5	14 1
	33.4	9 0	59.3	15 8	LO-TEMFRES		47.8	13 5
15	12.6	3 6	47.1	13 4	47.0	13 1		
	21.2	6 1	35.1	9 6	43.7	11 4	Percent Response Time	Absolute Response Time
	15.6	4 4	56.3	15 6	46.4	12 9		
	48.3	13 2	31.3	8 7	31.1	8 1		

Figure 14: The effects of relative temporal frequency on the perception of figure and ground for four spatial frequencies (0.5, 1, 4, 8 cpd). Figure legends are contained within the top-left bottom-right diagonal through the matrix. Each cell contains data from the four spatial frequencies used (beginning from the top line : 8, 4, 1, 0.5 cpd). Above the diagonal are the stimuli in which the rightward tilting cross contained the higher temporal frequencies. Below the diagonal are the stimuli in which the rightward-tilting cross contained the lower temporal frequency. The mean percent response time that the rightward cross was seen as background is in the right column of each cell. (We also recorded absolute response time, shown in the left column of the cell, but space does not allow discussion of this here.)

The results show that in general, the cross with the high temporal frequency, regardless of the spatial frequency in the regions, was perceived primarily as background. As the temporal frequency difference increased, the effect of the high flicker rate on determining a region as background also tended to increase for displays with spatial frequencies at 1 and 8 cpd. The results for the 0.5 and 4 cpd conditions were unclear. It appeared that the flicker "tuning function" for figure-ground perception is different at different spatial frequencies. This is revealed by comparing the percentage of time a flickering region was seen as background for 3.75, 7.5, and 15 Hz as a function of spatial frequency of the display in a condition in which the other cross is static.

We next held temporal frequency constant within conditions while varying spatial frequency. In one condition, the two crosses were filled with sinewave gratings of 1 and 4 cpd respectively. In the second condition, they were filled with gratings of 1 and 8 cpd respectively. For each of these two spatial frequency combinations, there were four temporal frequencies at which the entire pattern flickered: 0, 3.75, 7.5, and 15 Hz. When patterns flickered, the "on" half cycle on one cross coincided with the "off" half cycle of the other cross. The percent response time that the rightward-tilting crosses were seen as background was recorded. The results are shown in Figure 15.

TEMPORAL FREQUENCY (Hz)

		0		3.75		7.5		15	
Experiment 5 (1 and 4 cpd)	Lo-Spatfres	75.7	*21.4*	59.4	*16.8*	64.6	*18.7*	63.2	*18.5*
	Hi-Spatfres	31.8	*9.3*	30.0	*8.7*	30.7	*8.9*	42.9	*12.0*
Experiment 6 (1 and 8 cpd)	Lo-Spatfres	70.3	*20.2*	67.5	*18.5*	58.0	*16.4*	64.8	*18.4*
	Hi-Spatfres	13.5	*3.9*	21.1	*5.8*	25.5	*7.2*	9.0	*2.6*

Percent Response Time

Absolute Response Time

Figure 15: The effect of temporal frequency on figure-ground perception when regions differ in spatial frequency. In the top half of each cell are the stimuli in which the rightward-tilting cross contained the relatively lower spatial frequency sinewave grating, and in the bottom half are the stimuli in which the rightward-tilting cross contained the higher spatial frequency grating. The mean percent response time is shown for each temporal frequency in which the rightward-tilting cross was perceived as background.

The results indicate that when flicker was absent, the low spatial frequency region was seen predominantly as background. This is consistent with the previous findings of Klymenko and Weisstein (1986) and Wong and Weisstein (1987b). However, when the patterns flickered, the dominance of the low spatial frequency region as background decreased. This was especially noticeable when the regions differed by two octaves of spatial frequency. These findings suggest that the temporal response over-rides the spatial frequency response in figure-ground perception.

3.2 Contrast reversal flicker, spatial frequency, and figure-ground perception (Klymenko and Weisstein, 1987b)

We next ran the same temporal and spatial frequency conditions using a circular field divided evenly into two regions. The entire circle had a diameter of 5.66 degrees. The mean luminance of the circular region was 39.0 cd/m2. The surrounding background was 9.0 cd/m2. The experimental design was identical to the previously-described study except that instead of on-off flicker, contrast reversal flicker was used. The flickering gratings underwent contrast reversal with a square temporal waveform. For the patterns in which both regions flickered, the temporal onsets of the two gratings coincided. The results are shown in Figure 16. Four matrices of data show the effect of contrast reversal flicker on figure-ground perception when the spatial frequencies of the display were 0.5, 1, 4, and 8 cpd.

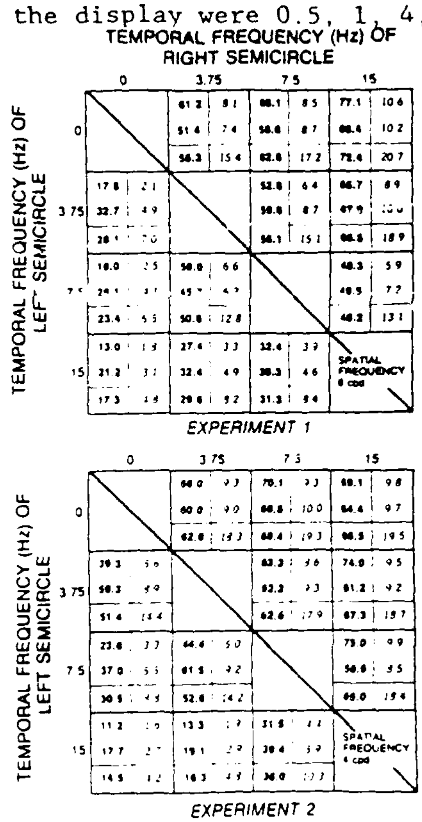


Figure 16: The cells show mean percent response time. Above the top-left, bottom-right diagonal are the responses for the right semicircle when it is undergoing the higher rate of contrast reversal flicker. Below the diagonal are the responses for the right semicircle when it is undergoing the lower rate of contrast reversal flicker. The lowest cell of the diagonal indicates the spatial frequency of the sinewave gratings tested in the condition

In general, the semicircle undergoing the highest rate of contrast reversal flicker was perceived as background more often than the region with the lower rate. The percentage of time the region with the higher flicker rate was seen as background increased as the difference between the flicker rates increased. This trend occurred for all the spatial frequency conditions. Also, as in the previous experiment, temporal freaquency overrides spatial frequency when the spatial frequencies vary among regions and the entire display is flickered. Overall, the results were similar to the studies using on-off flicker.

3.3 Stereopsis and flicker-induced depth (Klymenko and Weisstein, 1987c)

We next investigated the perceived depth segregation induced by flicker using a stereoscopic cancellation technique similar to the ones used by Brown and Weisstein (1987) and Wong and Weisstein (1987b,c). The display was the ambiguous picture consisting of two Maltese Crosses (see Figure 13, p. 17) covering a circular area with a diameter of 5.66 degrees. The two crosses were filled with sinewave gratings. The leftward-tilting cross was static and it was filled with a sinewave grating of 1.67 cpd. This was the region with adjustable disparity. The other cross was the "test" pattern. In one condition it was filled with a 1 cpd grating; in the second condition it was filled with a 4 cpd grating. Two types of square-wave flicker were used : on-off flicker and contrast reversal flicker. There were three flicker rates for each type of flicker : 3.75, 7.5, 15 Hz. During the trial, when the test pattern flickered, the observers adjusted the disparity of the static region such that the flickering and nonflickering crosses appeared coplanar. Stereopsis was created using typical anaglyphic methods in which one eye viewed the display through a red filter and the other eye viewed the display through a green filter. The results are shown in Table 3. Observers had to set regions stereoscopically in a depth direction opposite to that induced by flicker. The region with the higher relative flicker was always set stereoscopically behind the other region before both regions were perceived as coplanar.

Condition	Temporal Frequency (Hz)	Disparity Setting Mean	Disparity Setting SD	Individual Comparison Test
Stationary (control)	0	+.0150	.0518	--
Contrast reversal	3.75	+.0104	.0493	0.26
	7.5	-.0208	.0581	2.06
	15.0	-.0346	.0619	2.85*
On-off flicker	3.75	-.0144	.0738	1.69
	7.5	-.0599	.0661	4.30**
	15.0	-.0300	.0528	2.58*

Experiment 2

Condition	Temporal Frequency (Hz)	Disparity Setting Mean	Disparity Setting SD	Individual Comparison Test
Stationary (control)	0	+.0082	.0616	--
Contrast reversal	3.75	+.0054	.0351	0.19
	7.5	-.0233	.0571	2.14
	15.0	-.0409	.0705	3.34**
On-off flicker	3.75	-.0074	.0636	1.06
	7.5	-.0303	.0589	2.62*
	15.0	-.0186	.0623	1.82

Table 3 : The disparity settings required to null flicker-induced depth in each flicker condition for a 1 cpd and a 4 cpd stimulus. Disparity settings are given in degrees of visual angle. Positive numbers represent crossed disparity and negative numbers represent uncrossed disparity. Disparity settings less than -.0052 indicate that the adjustable region was set stereoscopically behind the "test" pattern.

<u>Discussion of Spatio-temporal results</u>

The results of the spatio-temporal studies lead to two amplifications of our organizing hypothesis. First, it appears that the effect of relative flicker on the perception of figure and ground depends on the spatial frequency content of the region. Second, it appears that the effects of spatial and temporal frequency on figure-ground and depth perception are not equally balanced. Rather, when flicker is introduced into a pattern whose regions vary in spatial frequency, the perception of depth and figure versus ground diminished or disappeared. The dominance of flicker over spatial frequency in inducing figure-ground perception suggests that temporal changes might emerge as a more important determinant of figure-ground perception than spatial changes. This leads to further questions not only about the role of flicker (as temporal frequency) in figure-ground perception but that of motion (in angular velocity) as well. Finally, because we are dealing with a perceptual effect, we need to examine simultaneous changes in flicker rate or angular velocity and spatial frequency. The perceptions arising from such changes cannot be predicted by simply holding one of the variables constant and changing the other because we cannot assume linear effects. Varying both temporal and spatial frequencies simultaneously will allow us to chart a spatio-temporal tuning response surface of figure-ground perception.

4. The Motion Response

We have just begun to explore the role of angular velocity in motion in the percepton of figure and ground. Below we report the findings of a preliminary study.

4.1 The role of velocity of moving fields in the perception of figure and ground (Wong and Weisstein, 1987d)

In this study we investigated how the velocity of moving fields affected the perception of a region as figure versus ground. We used a display consisting of a center and surround region filled with sinewave gratings. The display is shown in Figure 7a (p.11). The gratings were set to a spatial frequency of 1 cpd. One region of the display was always stationary while the other region moved at .5, 1, 2, 4, 8, or 16, degrees per second. The observer was instructed to monitor figure-ground perception in the same way described in the other experiments. We found that as the velocity increased, the moving grating was seen as ground more often than the stationary one. The effect reached a plateau at 8 deg/sec and no increase was observed at 16 deg/sec. The data suggest that the motion response in the figure-ground system might have an absolute upper velocity limit. This conjecture is reasonable given that images moving at high velocities appear blurred and fused (Graham, 1966; Smith 1987). At velocities between 15 and 30 deg/sec, directionality of motion can still be discriminated for a 1 cpd grating, but, perceptually, velocity does not seem to be specifiable (Smith 1987). Thus, in our displays, the fast-moving images might be "treated" equally by the motion response in the figure-ground system as blurred images. Indeed, when we moved the gratings at velocities of 24 and 32 deg/sec observers reported blurred or streaking in the images. This suggests that the motion response in figure-ground perception has a high velocity limit. Figure 17 summarizes the results.

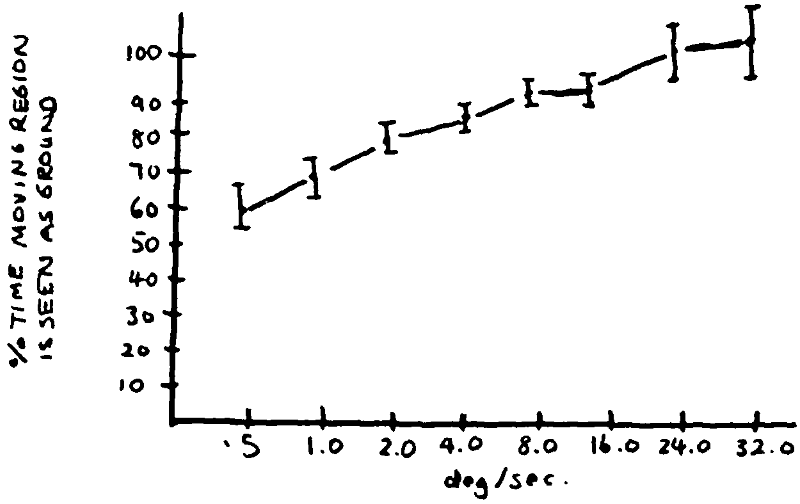


Figure 17 : The percentage of time a moving region is perceived as background as a function of angular velocity.

While we cannot make any conclusive statements about the relation between the role of motion and flicker in figure-ground perception given these exploratory findings, we can, however, make some comparisons between these data and our earlier findings. In particular, we can compare these findings to those of Klymenko, Weisstein, and Topolski (1987) in the condition in which a region filled with a 1 cpd grating was flickered at 3.75, 7.5, and 15 cpd. The percentage of time the flickering region was seen as background showed an inverted U-shaped function with a prominent peak at 7.5 Hz. This resembles the temporal tuning function obtained by Wong and Weisstein (1987a). However, the "velocity" function of "motion-induced ground" obtained in our preliminary study, while showing the same monotonic increase in the percentage of time the moving region was seen as ground as a function velocity up to 8 deg/sec, continues to stay high as angular velocity increases. Since the spatial frequency of the display used in this experiment is 1 cpd, we can convert the angular velocities into temporal frequencies and directly compare the Klymenko Weisstein and Topolski (1987) flicker data (The comparison is not perfect since Klymenko et al used square wave flicker, while in this study the moving sinewave gratings produced a sinusoidal temporal change on the retina.) Figure 18 compares the results of the three studies. These findings reveal complex relations between flicker, motion, and spatial frequency in the perception of figure and ground which we propose to study further in our continuation proposal.

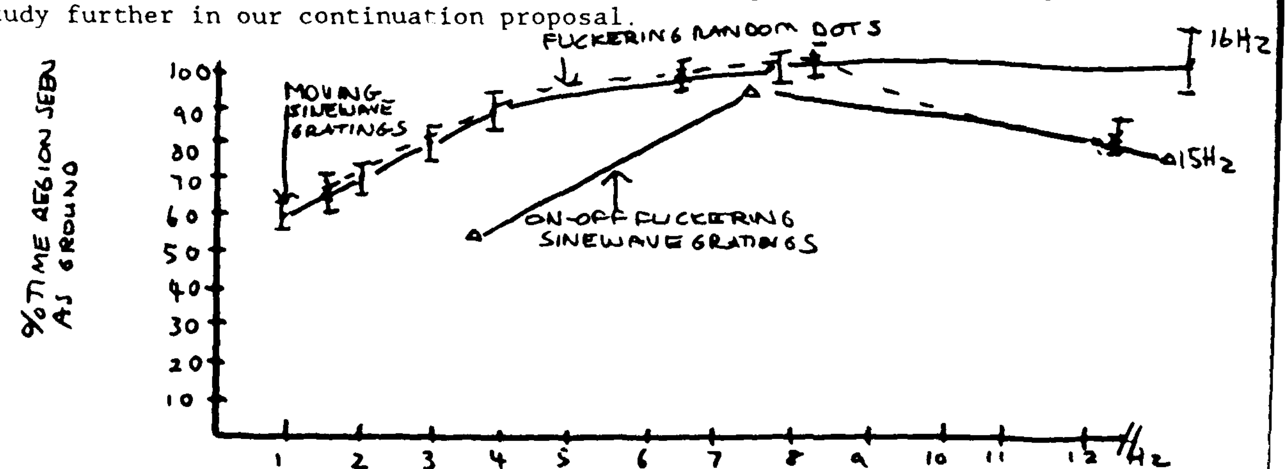


Figure 18: The tuning functions of "flicker-induced ground" compared with that of "motion-induced ground"

C. Related Studies

In addition to figure-ground investigations described above, we have also conducted a number of related studies which are described briefly below.

1.1 Experiments on Visual Phantoms

Brown and Weisstein (1987a) conducted a number of experiments investigating a phenomenon of moving visual phantoms first discovered by Tynan and Sekuler (1975). Two experiments examined the influence of two sensory factors on phantom visibility and perceived figure-ground segregation (Brown and Weisstein, 1985, 1988). Phantom visibility was systematically affected by manipulating the lightness of the occluder (the region where the illusion appears) and the way an inducing grating was flickered. Peak flickering phantom visibility occurred when occluder lightness was the same as the nonflickering stripes of a black and white square-wave inducing grating. Phantom visibility was optimal for a dark occluder when a standard on-off flicker (Type I flicker) was used, that is, when the off portion of the flicker cycle was a blank black field. When a reverse on-off flicker (Type II flicker) was used, (the "off" portion of the flicker cycle being a blank white field) phantom visibility was optimal for a light occluder. Phantom visibility was consistently absent when a gray occluder was used. With a gray occluder, the presence of clear edges between the inducing grating and occluder unambiguously defined an occluding surface, blocking the assimilation of brightness across the occluder (Grossberg and Mingolla, 1985). The early, low-level brightness information could not be overcome by higher-order interpretational or representational processes. When occluder lightness was similar to either the light or dark grating stripes the low-level brightness information was ambiguous allowing for the possibility of phantoms. When occluder lightness was ambiguous, an influence of flickering/nonflickering relations of the grating stripes became apparent. In both experiments phantom visibility was optimal when the stripes completing as phantoms were not flickering. This perception of nonflickering regions as a figure in front of the flickering regions is consistent with our results regarding flicker, figure-ground identification, and the perception of depth (see section above on figure-ground perception and the temporal response) even though portions of the perceived figure were illusory.

Using interposition as a cue to create different figure-ground and depth relations within various phantom inducing patterns, phantom visibility was measured while the local inducing environment of the patterns was kept the same (Brown, 1986, Brown and Weisstein, 1986; 1987a). Two measures of phantom visibility were recorded: phantom strength (percentage of viewing time phantoms were visible) and incubation time (time elapsed on each trial before phantoms were first reported). When the inducing pattern specified the phantom inducing regions as ground instead of figure, phantom strength was reduced by one half and incubation time was nearly doubled. These results indicate a link between phantom induction and the representation of figure and ground. When conflicting figure-ground and depth information is present the likelihood that the visual system will complete the representation declines.

A series of experiments showing that the perception of phantoms can affect the visibility of physically present targets further supports the conjecture that phantoms are perceived and represented as figural regions (Brown and Weisstein, 1988). Tilt discrimination of a line segment was found to be superior in phantom versus non-phantom regions, even though both regions were physically the same. There was no difference in performance between these regions when phantoms were not visible. These results paralleled those found by Wong and Weisstein (1982) on the discrimination of tilted line segments presented in figure and ground regions of an ambiguous picture.

1.2 Motion-induced contours

1.21 Type of motion

Klymenko and Weisstein (1984) reported that moving illusory contours may be functionally defined in terms of the type of motion which enhances them. They found that the motion-induced contour, an illusory dihedral edge, is enhanced by three-dimensional motion, but not by two-dimensional motion. Rotation-in-depth induced superior contour perceptibility compared to a stationary image, but rigid image motion did not. On the other hand, moving monohedral edges (e.g., see Tynan and Sekuler, 1975) may be induced or enhanced by two-dimensional motion, but three dimensional motion does not enhance contour perceptibility significantly more. Klymenko and Weisstein (1984) also found that contour perceptibility of the motion induced contour is inversely correlated with dihedral angle size, from 180 degrees to about 45 degrees. The contour is more perceptible for smaller dihedral angles.

1.22 Further three-dimensional motion

Since it has been well established that the motion-induced contour is due to three-dimensional motion, specifically rotation-in-depth, Klymenko, Weisstein, and Ralston (1987) tested additional three-dimensional image transformations. They found that looming (translation-in-depth under polar projection) did not produce a perceptible contour compared to rotation in depth. This is interesting in light of the fact that human observers cannot recover the spatial structure of a looming object, but they can recover the spatial structure of a rotating object (the well-known kinetic depth effect). The geometry of the looming transformation was analyzed as follows. The motion in a looming image can be geometrically decomposed into two motion components: a similarity transformation or size change, and a perspective change. It was suggested (also Klymenko and Weisstein, 1987a) that human inability to recover structure from looming was due to two factors. One, the image motion due to the size change (which contains no three-dimensional information) is large compared to the image motion due to the perspective changes (which contains the three-dimensional information). Two, the trajectories of the size change and the perspective change motion components are coincident and difficult for human observers to attend to separately. Thus the large size change motion component may "mask" the three-dimensional information in the perspective motion component. In fact, observers did not pick up three-dimensional structure from perspective changes. Klymenko, Weisstein, and Ralston (1987) also found that pure perspective changes (with the size change nulled) did not produce a contour, nor were they a good stimulus for recovering three-dimensional structure. Klymenko, Weisstein, and Ralston (1987) also found that size changes imposed on a figure rotating in depth, did not interfere with contour perceptibility or ability to recover structure from motion, thus indicating the robustness of the rotation in depth transformation. It is interesting to note that the set of experiments reported in Klymenko, Weisstein, and Ralston (1987) indicates a parallel between contour perceptibility and structure from motion.

1.23 Models of structure from motion

Klymenko and Weisstein (1987a) introduced a new model of structure from motion or the kinetic depth effect, which they dubbed the resonance theory of kinetic shape perception. This three-parameter model accounts for more of the structure from motion data than any previous model, as well as the motion-induced contour data briefly summarized above. In addition, the model accounts for other perceptual phenomena, such as the pausing effect, the Ames trapazoidal illusion, the rubber pencil illusion, and the attenuacion of rigidity of rotating objects by perspective. In addition, Klymenko and Weisstein (1987a) clarify some philosophical problems concerning illusions and discuss ecological optics.

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Wong, E., and Weisstein, N. (1987b) Spatial frequency, perceived depth, and figure-ground perception. Submitted.

Wong, E., and Weisstein, N. (1987c) Spatial frequency, perceived depth, and figure-ground perception. Submitted.

Wong, E., and Weisstein, N. (1987d) The role of velocity of moving fields in the perception of figure and ground. In preparation.

APPENDIX

List of publications, presented papers, submitted papers, and papers in preparation during the funding period

Reprints included in this report are indicated by (*)

Brown, J.M. (1986) Phantom figures affect orientation discrimination performance. Paper presented at Aldephi International Conference on Illusory Contours. Abstract appeared in conference report, Perception and Psychophysics, 39, 217.

Brown, J.M., and Weisstein, N. (1985a) Flickering phantoms: A figure-ground appaproach. Paper presented at Eastern Psychological Association Meeting, Boston.

Brown, J.M., and Weisstein, N. (1985b) Spatial frequency influence on the perception of depth. Paper presented at Optical Society of America Meeting, Washington, D.C.

Brown, J.M., and Weisstein, N. (1986) Depth information without phantom inducing regions can influence phantom vsibility. Paper preented at Eastern Psychological Association Meeting, New York.

Brown, J.M., and Weisstein, N. (1987) A spatial frequency effect on perceived depth, Perception and Psychophysics, accepted.

Brown, J.M., and Weisstein, N. (1988a) A phantom context effect: visual phantoms enhance target visibility. Perception and Psychophysics, 43, 53-56. (*)

Brown, J.M., and Weisstein, N. (1988b) The influence of occluder lightness and flicker type on flickering phantom visibility. In preparation.

Brown, J.M., and Weisstein, N. (1988c) A new perceived depth effect on phantom visibility. In preparation.

Brown, J.M., Weisstein, N., and Klymenko, V. (1986) Spatial frequency can influence the organization of regions in depth. Paper presented at the Association for Research and Ophthalmology Meeting, Sarasota, Florida.

Klymenko, V., and Weisstein, N. (1983) The edge of an event: invariants of a moving illusory contour. Perception and Psychophysics, 34, 140-148.(*)

Klymenko, V., and Weisstein, N. (1984a) Structure and motion: illusory contours and image transformations. Paper presented at Psychonomics Society Meeting.

Klymenko, V., and Weisstein, N. (1984b) The razor's edge: a dichotomy between monohedral and dihedral edge perception. Vision Research, 24, 995-1002.(*)

Klymenko, V., and Weisstein, N. (1985) Structure and motion: illusory contours and projective transformations. Paper presentedt at Adelphi International Conference on Illusory Contours.

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Weisstein, N., and Wong, E. (1988) The effects of figure-ground perception on metacontrast masking. In preparation.

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Wong, E., and Weisstein, N. (1987d) The effect of perceived velocity on the perception of figure and ground. In preparation.

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