

A psychoanatomical investigation of the blanking phenomenon

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ABSTRACT

One cannot detect a white disk located at least 15 degrees from fixation in an intersection of gray alleys that define a grid of black squares. A psychophysical examination of the anatomical locus of this “blinking phenomenon” is reported here. Stimuli were presented dichoptically; disk threshold was measured with fixed-step staircases. Three dichoptic experiments were developed employing different stimuli. Simple dichoptic presentations implied both pre- and post-fusion contributions. One follow-up experiment verified pre-fusion contributions, while another implicated post-fusion mechanisms. These results indicate that the blanking phenomenon has contributions from multiple sites in the visual system.

1. INTRODUCTION

Psychophysical examination of visual phenomena has yielded extensive information regarding the structure and function of the human visual system. Recently, the psychophysical analysis of a visual illusion termed the “blinking phenomenon” has been reported (McAnany and Levine, 2002, 2003, 2004). The blinking phenomenon is elicited by black squares on a medium gray background, arranged such that the squares delineate a set of intersecting orthogonal gray “alleys.” If a disk lighter than the background alley-gray is centered in an intersection approximately 15 degrees or more from fixation, the disk is not perceived. Fixating on the lower grid of Figure 1 provides a demonstration of the blinking phenomenon. When fixation is appropriately distant from the upper grid, the light disk disappears. Conversely, disks darker than the background alley-gray remain visible; when fixating the upper grid in Figure 1, the dark disk in the lower grid remains visible.

Figure 1 about here

Conditions under which the blinking phenomenon occurs and factors affecting the efficacy of the illusion have been examined (McAnany and Levine, 2002, 2003, 2004). For example, the blinking phenomenon is evident for a light disk presented with a reduced grid consisting of an intersection delineated by just four black squares (McAnany and Levine, 2002, 2003, 2004). While the inverse arrangement of four or more white squares surrounding a dark disk on the same background alley-gray also elicits the blinking phenomenon, it is somewhat less effective.

The phenomenon develops immediately and is present with trial durations less than 250 ms. With longer presentations, the effect persists for as long as fixation is approximately maintained. If fixation is appropriately far from the disk (approximately 15 degrees or greater), small saccades do not disrupt the phenomenon (this can be verified with Figure 1). Additionally, the disk must be centered in an intersection for blanking to occur, as a disk centered as little as one disk radius from the center of the intersection is visible. Finally, the onset and offset of the grid and disk must be simultaneous; if the grid and disk are presented asynchronously, the effect is disrupted. Thus, the blanking phenomenon is a novel form of visual disappearance that is not dependent on adaptation, motion, or masking.

Other than the aforementioned rudimentary characteristics, little else is known regarding the mechanisms underlying the blanking phenomenon. In an effort to gain a greater understanding of the effect, this study examines the anatomical and physiological underpinnings of the blanking phenomenon as inferred through psychophysical examination. We employ a strategy that uses the site of binocular fusion as a marker for localizing events that occur proximal or distal to that reference point (the psychoanatomical approach: Blake, 1995).

Experiment I was designed to parse the anatomical contributions to the blanking phenomenon from pre- and post-fusion sites. In experiment I, a light disk was presented to one eye and the grid of black squares was presented to the other eye. Disk contrast threshold was measured to determine the efficacy of the blanking phenomenon. Results of experiment I imply both pre- and post-fusion contributions to the blanking phenomenon.

Experiment II was designed to specifically reveal pre-fusion contributions by comparing contrast thresholds from two different conditions. In the “same-polarity” condition, neither eye received a stimulus that would induce blanking, while in the “opposite-polarity” condition each eye received a stimulus that would induce blanking. As will be discussed in section 4.2, these two conditions were created to appear identical to high-level (post-fusion) cortical processing centers while being readily discriminable by lower-level (pre-fusion) areas. If the contrast thresholds are different between these two conditions, a pre-fusion contribution to the blanking phenomenon can be inferred, as only the pre-fusion peripheral paths should have the ability to differentiate between the same- and opposite-polarity conditions.

Experiment III was designed to verify post-fusion contributions to the blanking phenomenon. In experiment III, a light disk appeared to be centered in an intersection of black squares; however, the disk was presented in a different plane than the grid (disparity condition). The contrast threshold in the disparity condition was compared to that obtained when disks appearing in both eyes were shifted in the same direction by the same amount as in the disparity condition (offset condition). If the blanking phenomenon is greater in the disparity condition than in the offset condition, a post-fusion contribution can be inferred since neither eye alone can distinguish between these two conditions.

2. METHODS

2.1 Subjects

The authors (males 24 and 60 years of age) and one volunteer naïve to the intent of the research (female 24 years of age) participated in all three experiments (subjects 1, 2, and 3, respectively). All subjects had normal or corrected-to-normal visual acuity and normal stereopsis. The experimental protocol and process of consent were approved by the University of Illinois at Chicago Institutional Review Board.

2.2 Apparatus and Calibrations

A chin-rest supported the subject's head, which was located 32 cm from a computer monitor in a dark room. The total path length from the subject's eyes to the monitor was 37 cm. Stimuli were generated by an IBM Pentium III computer running Windows 98 and were displayed on the screen of an EIZO 19" FlexScan FX•D7 monitor (1024x768 pixels, 85 Hz refresh rate). One component of the stimulus, chosen at random, was presented on one half of the computer monitor, and the remaining component was presented simultaneously on the other half of the same monitor. A first-surface mirror stereoscope permitted fusion of the images on the two halves (see Figure 2A for a schematic of the stereoscope).

Figure 2 about here

The shape of the subject's horopter was taken into account to ensure proper alignment and fusion of the stimuli appearing in the left and right eyes. Alignment was calibrated using a modified Nonius method of horopter correction (for an explanation of

the Nonius method of horopter correction, see Moses and Hart, 1987). The modified Nonius method employed in this study used a series of horizontal and vertical lines centered where each intersection was to appear during testing. Specifically, a vertical line originating from the center position of a future intersection and extending upward approximately 0.9 deg appeared in one eye while the other eye simultaneously received a similar line originating from the same point and extending downward. These lines were presented for 224 or 280 ms (trial duration for that subject during testing); in successive presentations, the subject's task was to align these two lines. This arrangement was also repeated with horizontal lines to determine the proper vertical alignment. The process of determining the proper horizontal and vertical alignments was iterative, as misalignment in one direction was found to affect judgment slightly in the other direction. To achieve alignment for the intersection that was to receive the disk on each trial, the patterns used during testing were shifted by the number of pixels that the nonius lines were shifted.

2.3 Time-course and Display

The subject adapted to the background alley-gray for 30 s at the onset of each block of trials. Then, while fixating on a central target, the subject initiated the stimulus presentation by key-press; the stimulus appeared after a 500 ms delay. The central fixation target consisted of a "bulls-eye" appearing in 3D (see Figure 2B). To preclude changes in fixation, the stimulus and fixation point were replaced by the background alley-gray either 224 or 280 ms (depending on the subject) after its onset. The disappearance cued the subject to respond; the subject responded by key-press, and the fixation target reappeared. On each trial, a disk appeared in one of three possible intersections (left,

middle, or right); the subject's task was to determine which intersection contained the disk (3AFC). Stimuli were presented at random with equal probability in the upper and lower visual fields (above and below fixation) to discourage inappropriate fixation (refer again to Figure 1). There were no time constraints for responding or for initiating the subsequent trial, and no feedback was given. Timing of the stimulus duration was confirmed by oscilloscope measurement.

Display luminance was calibrated with a Minolta luminance meter (LS-110). RGB machine units (the binary digits sent to the guns) were converted to luminance values derived from the best-fit quadratic curve. For comparing light and dark disks, luminance values were expressed as the absolute value of contrast according to the Weber contrast formula:

$$(1) \quad C_i = |(L_i - L_{\text{gray}}) / L_{\text{gray}}|$$

Where L_i represents the disk luminance and L_{gray} is the luminance of the background alley-gray. In all conditions, the background alley-gray was constant, but specific to the subject (31.3 cd/m² for subject 1 and 35.1 cd/m² for subjects 2 and 3). To make the light and dark disk efficacies equal, the background alley-gray was set so that the absolute value of the contrast threshold of light disks with white squares was equal to that of dark disks with black squares. The black squares were set to 0.3 cd/m², white squares to 93.8 cd/m², and the disk luminance ranged between those values. For subject 1 the stimulus presentation duration was 224 ms, for subjects 2 and 3 the stimulus presentation duration was increased to 280 ms to avoid floor effects.

2.4 Threshold Determination by Adaptive Fixed-Step Staircase

An adaptive fixed-step staircase (FSS) protocol was used to determine threshold values for the stimuli examined (see Treutwein, 1995 for a review). These FSSs provide rapid and accurate measurements of threshold. FSSs were interleaved randomly to obtain threshold values for disks that appeared above and below fixation in the left and right eyes, respectively. For each block of trials, a preliminary search to gain an estimate of the subject's threshold began at a suprathreshold value (white or black), and descended in large steps toward (often beyond) the subject's threshold. In conditions where the contrast threshold could be estimated, the staircase starting value was set appropriately and the preliminary search was omitted.

Upon termination of the preliminary search, a 1 down/2 up rule was initiated (one incorrect answer increased the absolute value of disk contrast; two successive correct responses to the same stimulus level were required to decrease the absolute value of disk contrast). The magnitude of contrast change for incorrect answers was twice that for correct answers. This provides a target estimate of the 82% correct point on the psychometric function (Garcia-Perez, 1998). Step size was limited by the 8-bit per gun hardware available for the production and display of the stimuli, so the smallest step change was 1 unit in the RGB machine metric. Note that while the luminance step changes were not quite equivalent across all luminance levels, over the small excursions near FSS convergence the gamma function was essentially linear.

Each FSS was terminated after at least 16 reversals in direction were completed (unless obviously pinned at a limit of the luminance range). The average of the last six reversal values was taken as the threshold for that FSS. Each FSS was plotted and

examined as a means of confirming that a valid asymptote had been attained.

3. EXPERIMENT I: DICHOPTIC ARRANGEMENTS

3.1 Introduction to Experiment I

Experiment I sought to identify the anatomical locus of the blanking phenomenon through the use of dichoptic stimulus presentations. It is often possible to determine the origins of illusory phenomena through the use of stereoscopic presentation (Julez, 1971). One method of determining the anatomical origin is to present one eye with partial information while the other eye receives the necessary remaining component. Since neither eye receives the complete image, there must be binocular fusion to recreate the original stimulus. If the illusion persists when segregated across eyes, its source is likely to be at or after the site of fusion (at a cortical level), as this arrangement prohibits the illusion from being generated within either eye (or pre-fusion pathway). Conversely, if the phenomenon does not persist when segregated across eyes, it is likely that the illusion is generated before the site of fusion in the separate (peripheral) paths, indicating that retinal or geniculate processing is largely responsible.

3.2 Methods of Experiment I

A light disk on a field of background alley-gray was presented to one eye while a grid of black squares on the same background alley-gray was presented to the other eye (Figure 3A). To facilitate proper alignment of the grid and disk, a black outline alignment grid was presented to the eye receiving the disk. The outline alignment grid was selected on the basis that it did not itself induce the blanking phenomenon. On each trial, the disk and

outline alignment grid combination was equally likely to appear in the left or right eye; the grid of black squares always appeared in the other eye. In the dichoptic arrangement (Figure 3A), neither eye alone received a stimulus that was capable of inducing blanking. Thus, if the blanking phenomenon were observed, it could be inferred that the effect has components from post-fusion sites.

Pilot work, which did not include an outline alignment grid, suffered from inconsistent alignment of the grid and disk. Without the outline alignment grid, subjects reported that the disk often appeared outside the intersection; consequently, the disk was easily visible on many trials. However, when the outline grid was present in the eye receiving a dark disk, the disk appeared properly centered in the intersection. To ensure that the outline alignment grid did not itself affect threshold, disk threshold was calculated when the outline alignment grid and a light disk were both presented to one eye while the other eye received a field of background alley-gray (Figure 3B).

Figure 3 about here

Two additional control arrangements compared the contrast thresholds obtained in the absence of blanking and when blanking was fully present. The first control arrangement consisted of a light disk presented to one eye on the background alley-gray in the absence of squares, while the other eye received only a field of background alley-gray (Figure 3C). The second control condition consisted of a light disk and a grid of black squares presented to one eye and a field of background gray presented to the other (Figure 3D). The former control arrangement provided the lowest expected contrast threshold value for disks, and the latter provided the measurement for maximal blanking. Both

controls accounted for the possibility of reduced contrast due to the alley-gray field presented in the eye not receiving the relevant part of the stimulus.

3.3 Results of Experiment I

Figure 4 depicts the contrast threshold values for each subject in experiment I. Each subject completed 4 staircases (approximately 500 trials total). A repeated measures ANOVA including all subjects and all conditions with a measurable threshold revealed significant differences among conditions in experiment I, $F(2,22)=69.17, p<0.001$. Bonferroni corrected post-hoc tests for the comparisons of interest will be discussed below. Conditions in which maximal blanking occurred were not included in this analysis as a valid threshold could not be obtained so variance was zero.

Threshold for the control condition with just the outline grid and disk (Figure 3B and stippled bars in Figure 4) was not significantly different from the control arrangement lacking squares (Figure 3C and black bars in Figure 4), $t=0.35, p>0.05$. This indicates that the outline alignment grid itself does not significantly increase threshold or induce blanking. In the dichoptic condition (Figure 3A & gray bars in Figure 4), contrast threshold was significantly higher than the outline alignment grid alone condition, $t=10.00, p<0.001$ and the no squares condition, $t=10.36, p<0.001$; the blanking phenomenon was present, but not maximal. Although contrast threshold was high in the dichoptic arrangement, observers were able to identify the disk location at a rate greater than chance. This difference is clear when comparing the threshold of the dichoptic condition with attempts to obtain a threshold when one eye received the grid of black squares and the light disk while the other eye received only the background alley-gray (Figure 3D &

striped bars in Figure 4). There are no error bars for this condition because the disk was never detected at the maximum available contrast. Thus, blanking was present in the dichoptic condition, but it was not as effective as when one eye received the full stimulus and the other eye received the background alley-gray field. This intermediate level of blanking in the dichoptic condition implies that both pre- and post-fusion mechanisms underlie the blanking phenomenon.

Figure 4 about here

4. EXPERIMENT II: COMPLEMENTARY ARRANGEMENTS

4.1 Introduction to Experiment II

Since experiment I indicated the possibility that both pre- and post-fusion mechanisms play a role in the blanking phenomenon, a second experiment was designed to explore further the putative pre-fusion mechanisms. In experiment II, the anatomical locus of the blanking phenomenon was examined psychophysically by presenting a grid and disk to each eye; however, the contrast of the stimulus appearing in each eye was opposite. Pilot work indicated that a stimulus consisting of a full grid and disk presented to each eye is easily aligned. Contrast threshold from two arrangements were compared (the “opposite-polarity” and “same-polarity” conditions).

4.2 Methods of Experiment II

The opposite-polarity condition consisted of a light disk and a grid of black squares presented to one eye and a dark disk and a grid of white squares presented to the other

(see Figure 5A). In this condition, each eye received a stimulus that induces blanking. The same-polarity condition consisted of the presentation of a light disk and a white grid of squares to one eye and a dark disk and a black grid of squares to the other (see Figure 5B). In this condition, each eye received a stimulus that would not effectively induce blanking. Finally, the lowest expected contrast threshold was determined by presenting a light disk to one eye and a dark disk to the other, both in the absence of squares.

As in experiment I, the component of the stimulus appearing in a given eye was determined randomly, and the other eye received the appropriate counterpart. The disk always appeared in the same intersection on grids presented to each eye (or the same location when no intersection was present). Note that the absolute contrast value of the light disk presented to one eye and the dark disk appearing in the other was always the same.

Figure 5 about here

An assumption is made regarding the higher level processing of these stimuli: namely, the information reaching higher cortical areas is identical in the same and opposite-polarity conditions (a dark/light disk and a black/white grid of squares). Using intermingled rivalrous images, other investigators have shown that the brain neglects eye-of-origin information at high-level processing stages (Kovács, Papathomas, Yang, Feher, 1996; see also Logothetis, Leopold, and Sheinberg, 1996). Through different methods, other investigators have reached the same conclusion. Ono and Barbeito (1985) devised several conditions in which subjects were asked to make utricular discriminations employing various cues. These authors found that subjects could not make use of any cue

to identify the eye-of-origin; they conclude that eye-of-origin information does not enter conscious awareness.

If the blanking phenomenon is occurring in higher-level sites after the point of fusion, the contrast thresholds of the same and opposite conditions should be equal (because the information reaching these higher level sites is indistinguishable between the two conditions). If the contrast thresholds obtained in these two conditions are not equal, contributions from a lower-level pre-fusion locus must be implicated, as only the individual eyes (or perhaps the earliest cortical areas) are able to differentiate between the opposite and the same-polarity conditions.

4.3 Results of Experiment II

Each subject completed 4 staircases (approximately 500 trials total). Contrast threshold for the opposite-polarity condition could not be determined; even at the maximum available contrast, the subjects could not identify the intersection that contained the disk (see Figure 6, striped bars). Conversely, in the same-polarity condition the subjects were able to identify the intersection containing the disk (the average contrast threshold across subjects was 0.944, Figure 6, stippled bars). Thus, when each eye received a stimulus capable of inducing the blanking phenomenon, blanking was present. When each eye did not receive a stimulus that could induce blanking, the brain did not combine the stimuli from the individual eyes to induce an equivalent effect. A *t*-test could not be computed to determine differences for the same versus opposite-polarity conditions, as disks in the opposite-polarity condition were never visible (variance was zero). However, the 95% confidence intervals of the same-polarity condition fall below the maximum contrast

available (the value obtained in the opposite-polarity condition). Were additional contrast available, the contrast threshold of the opposite-polarity condition would have been higher.

Figure 6 about here

5. EXPERIMENT III: DISPARITY ARRANGEMENTS

5.1 Introduction to Experiment III

Experiment III sought to verify the post-fusion mechanism implied by experiment I. In experiment III, disk contrast thresholds from two conditions were compared (the “disparity” and “offset” conditions).

5.2 Methods of Experiment III

In the disparity condition, the disk appeared to be centered on an intersection but in a different plane than the grid (Figure 7A). The disk appeared either in front of or behind the grid; the plane in which the disk was presented was determined randomly, but the amount of disparity was constant. Disparity was induced by shifting the disk appearing in each eye by the same amount in opposite directions. No significant differences in contrast threshold were found between disks that appeared to be in front of or behind the grid.

Contrast threshold from the disparity condition was compared to a control condition in which the disk was offset from the center of the intersection (offset condition, Figure 7B). The disk in this condition appeared in the same plane as the grid, but was

offset in the same direction in each eye by the amount used to induce disparity in the disparity condition (one disk radius). This control condition was created to assess the effects on contrast threshold when the disk is not centered in the intersection.

Figure 7 about here

Since the disk in each eye was shifted from the center of the intersections in both the disparity and offset conditions, neither eye in either condition received a stimulus that should induce optimal blanking. Note that the stimuli presented to either eye were identical in both the disparity and offset conditions. If threshold is higher in the disparity condition, it can be inferred that the blanking phenomenon has components from post-fusion sites.

5.3 Results of Experiment III

Contrast threshold values for experiment III for each subject are shown in Figure 8. Data comprise 12 staircases for Subject 1, 8 for subject 2, and 4 for subject 3. Contrast threshold for the disparity condition (Figure 8, stippled bars) was higher than the contrast threshold for the offset condition (Figure 8, gray bars). Repeated measures ANOVA revealed these differences to be significant $F(1,23)=21.54, p<0.001$. Post hoc *t*-tests reveal significant differences for subjects 1 and 3; for subject 2 the trend is clearly in the same direction.

The error bars indicating 95% confidence intervals are inflated due to differences in threshold obtained from presentations in the upper and lower visual fields. As observed

in previous work (McAnany and Levine, 2004), contrast threshold is consistently lower in the lower visual field than in the upper visual field. The error bars represent data obtained from both the upper and lower visual fields and are therefore larger than they would be if the fields were considered independently.

Neither eye alone received a stimulus that induced strong blanking, but upon fusion in the disparity condition the disk appeared centered and was more difficult to detect. However, comparison of the striped bars in Figure 4 to the stippled bars in Figure 8 shows that maximal blanking was not achieved in the disparity condition. These results confirm the tentative conclusion drawn from experiment I: in addition to pre-fusion contributions, there are significant contributions to the blanking phenomenon from post-fusion sites.

Figure 8 about here

6. DISCUSSION

6.1 Could binocular rivalry explain these results?

The possibility that binocular rivalry has confounded these results has been examined and rejected. Binocular rivalry occurs when the two eyes are presented with disparate stimuli. Rather than summing or fusing the stimuli, perception is dominated by one eye or the other. Thus, during binocular rivalry, the stimulus in one eye is suppressed while that in the other is perceived. For the following reasons it is unlikely that binocular rivalry influenced the results of these experiments:

- Subjects fixated on a target that appeared in 3D. If rivalry were present before or during the stimulus presentation, the 3D effect would not have been obtained (during rivalry, the fixation mark would have appeared two-dimensional).
- The stimulus presentation time was less than 0.3 s, and the required time of onset of rivalry is substantially longer (Chen and He, 2003; Blake, 2001). Previous research has shown that binocular rivalry is rarely experienced when stimuli are presented briefly; instead, perceptual superimposition of the stimuli results (Blake, 2001; Blake, Westendorf, and Yang, 1991).
- Suppression of one eye would result in a random response on approximately 50% of the trials, and this level of randomness would result in an unstable staircase. The slopes of the staircases in experiment I were compared to the slope of a staircase obtained under conditions of simulated rivalry. To simulate rivalry, a light disk and a grid of white squares were presented to both eyes (a condition in which the disk is detectable), but on 50% of the trials a random response was substituted for the subject's answer. This method of random answer substitution mimics the effects of binocular rivalry, assuming the information from one eye is suppressed on each trial. The staircase obtained from this simulation is presented in Figure 9A. This figure shows that the staircase slopes upward and is unstable (a valid asymptote is not reached). In this condition the subject answers with approximately 66% accuracy (assuming 100% correct on half of the trials and a random answer is substituted on the remaining 50% of the trials; however, the random answer would be correct 33% of the time). Typical staircases obtained from a condition in which maximal blanking was present (light disks with black squares presented to one

eye) are shown in Figure 9B. These staircases are characterized by an initial maximally steep slope until the staircase “locks” at the highest available contrast. In Figure 9B, the subject is answering with approximately 33% accuracy (random) thus these staircases follow a different pattern than those shown in Figure 9A. The clear difference between staircases obtained from conditions of rivalry and blanking further support the conclusion that blanking cannot be explained by binocular rivalry. Finally, a representative staircase obtained from experiment I is presented in Figure 9C for comparison. Staircases in all experiments were examined and no staircase that provided a measure of threshold showed the instability or large slope like that of Figure 9A.

Figure 9 about here

6.2 Interpretation of the experiments

The mechanisms underlying the blanking phenomenon are complex and act at multiple sites in the visual system. The presence of blanking when the stimulus was segregated across eyes in experiment I indicated that post-fusion sites are involved in the blanking phenomenon. However, maximal blanking was not induced in the dichoptic presentations.

The absence of maximal blanking in experiment I could be attributed to one or more of at least three distinct possibilities. First, there is the possibility of improper alignment. If, on occasion, the disk appeared to fall outside the intersection, the observer would be able to identify the correct disk location with ease. However, the alignment grid should have prevented this, and subjects did not report disks falling outside of the intersection. Second, the effective contrast of the squares may have been reduced. Superimposing the background alley-gray field appearing in one eye on the squares

appearing in the other eye could reduce their effective contrast. A reduction in effective contrast decreases the efficacy of the blanking phenomenon and lowers threshold. This possibility is unlikely as maximum blanking was attained when the grid and disk were presented to one eye and the other eye received a field of background alley-gray. Finally, pre-fusion mechanisms may facilitate blanking. Contributions from low-level pre-fusion sites would not be available in the dichoptic presentations; without these contributions, blanking may not be as effective and threshold would be lower. The presence of strong but not maximal blanking in the dichoptic arrangement indicates that the blanking phenomenon likely has contributions both from high-level post-fusion sites and from low-level pre-fusion sites.

In experiment II the presence of maximal blanking in only the opposite-polarity condition confirms that the blanking phenomenon has contributions from low-level sites (prior to the locus of fusion). When each eye received a stimulus that induced blanking (even when the stimulus presented to each eye was different), the blanking phenomenon was present. Conversely, threshold was lower in the same-polarity arrangement. The cortex did not extract information from one eye (for example, a light disk) and combine it with information from the other eye (the black grid of squares) to induce the blanking phenomenon. Note that the subjects reported proper alignment of the grids and disks in the same-polarity condition; it can safely be assumed that alignment was also correct in the opposite-polarity condition, as the disks were not visible. Thus, improper alignment is not likely to have contributed to these results.

Threshold was higher in the same-polarity condition (Figure 6, stippled bars) than in the complementary disk condition lacking squares (Figure 6, black bars). Repeated measures ANOVA revealed these differences to be significant, $F(1,11)=74.19, p<0.001$. From this result alone, it is difficult to determine whether the threshold increase in the same-polarity condition is due to weak blanking or to a contrast reduction resulting from the presence of squares. Previous work has shown that the threshold of a disk surrounded by squares of the same polarity is higher than that of the disk presented alone. This increase in threshold is consistent with a decrease in effective contrast due to the surrounding squares (McAnany & Levine, 2004). The likelihood of a similar effect inflating threshold in the complementary condition is explored in the next paragraph.

The effect of squares on the same-polarity condition was assessed by comparing two ratios (the “with- to without-squares ratio” and the “complementary ratio”). The “with- to without-squares ratio” was defined as the ratio of the threshold of a disk presented with squares of the same-polarity to that of the disk presented in the absence of squares. Disk contrast threshold was determined separately for dark disks presented with black squares, and light disks presented with white squares. Similarly, disk contrast threshold values were separately obtained for dark and light disks presented in the absence of squares. The “complementary ratio” is the ratio of the threshold of the same-polarity condition (Figure 6, stippled bars) to the threshold of the complementary disks presented without squares (Figure 6, black bars). Across subjects, the range of threshold ratios for the “with- to without-squares ratio” ranged from 5.4:1 to 8.1:1 (the mean was 6.6:1). The “complementary ratio” showed a similar spread, with a mean of 6.4:1. While only an approximation, the similarity of these ratios indicates that the threshold increase in the

same-polarity condition (relative to the complementary no squares condition) can be largely explained by the contrast reduction due to the presence of squares. The threshold increase can be accounted for without invoking post-fusion processes.

The contribution to the blanking phenomenon from post-fusion sites determined in experiment III further confirms the other tentative conclusion drawn in experiment I. When the disk was not centered in the intersection in each eye, but upon fusion appeared to be centered in front of or behind the grid (disparity condition), the threshold was higher than in the offset condition. The threshold was significantly lower when the disks were presented outside the intersection but did not appear to be centered when the images were fused (offset condition). As in experiment I, maximal blanking was not achieved in the disparity condition. This absence of maximal blanking may be attributed to contributions from pre-fusion sites, or failure of the disk to appear perfectly centered due to eye dominance. Alternatively, failure to achieve maximum blanking could be related to the disks only having the appearance of being aligned with the intersection, but not actually appearing *in* the intersection due to its appearance in a different plane.

6.3 Mechanisms of blanking

A dual-stage theory can be invoked to explain the processing that results in the blanking phenomenon. First, lateral antagonism in pre-fusion sites initiates the blanking phenomenon. Lateral antagonism within the retina was also proposed to account for the mechanisms involved in similar illusory stimuli (the scintillating grid: Schrauf, Lingelbach, Wist, 1997, and the Hermann grid: Spillman, 1994). Receptive fields centered on intersections receive much greater antagonism than receptive fields located within alleys

(Spillman, 1994). This increase in antagonism increases the threshold for light disks. The possible role of ON and OFF receptive field mechanisms has been described in detail elsewhere (McAnany and Levine, 2004).

Post-fusion processing at higher-level cortical sites constitutes a second stage. Processing at this stage could be similar to the proposed mechanisms in the retina (lateral antagonism), or perhaps a more complex mechanism may be present. Several mechanisms could be proposed to account for the cortical components underlying the blanking phenomenon. Unfortunately, none seem entirely sufficient to explain the phenomenon.

First, it is unlikely that the attentional mechanisms that have been invoked to explain other forms of visual disappearance (motion induced blindness, Bonneh, Cooperman, Sagi, 2001) are relevant to the blanking phenomenon. Bonneh's attention-driven "winner-takes-all" model of perception proposes a suppression of attention shifting between objects in a scene. The "winner-takes-all" theory posits that a high contrast background produces a salient and powerful stimulus, and a small disk of opposite contrast appearing at an intersection may be perceived as a separate feature of the stimulus. The small disk of opposite contrast may be neglected because attention is focused on the complex high contrast background. Conversely, a disk of similar contrast to the squares is likely to not be interpreted as a separate entity; thus, no shift in attention is required. Although attractive, this theory is unlikely to be applicable to the cortical mechanism underlying the blanking phenomenon. The attentional demands of identifying a disk falling in an intersection and identifying a disk falling slightly outside of an

intersection are essentially equal, whereas threshold values obtained from these arrangements are decidedly not.

Another possible cortical mechanism that might be postulated to underlie the blanking phenomenon is feature grouping across distance. Schrauf *et al.* (1997) proposed that the scintillating grid illusion, a related phenomenon, may be a result of the cortical processing of a repeating grid pattern. Thus, a pattern repeating in space (recruiting repeating cortical columns) could be necessary for the blanking phenomenon to occur. However, this is also unlikely as effective blanking is present in stimuli consisting of only a single disk and an intersection composed of four squares (McAnany and Levine 2002, 2004).

In conclusion, the work presented here adds to the growing body of information regarding visual disappearance in normal observers, and more specifically, the blanking phenomenon. Future work is needed to clarify the cortical mechanisms involved in the blanking phenomenon.

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References

Blake, R. (1995). Psychoanatomical strategies for studying human vision. In *Early vision and beyond*, T. Papathomas, C. Chubb, E. Kowler, A. Gorea (Eds), MIT Press

Blake R (2001). A primer on binocular rivalry, including current controversies. *Brain and Mind*, 2, 5-38.

Bonneh, Y. S., Cooperman, A., Sagi, D. (2001). Motion-induced blindness in normal observers. *Nature*, 14, 798-801.

Garcia-Perez, M. A. (1998). Forced-choice staircases with fixed step sizes: asymptotic and small-sample properties. *Vision Research*, 38, 1861-1881.

Julez, B. (1971). Foundations of cyclopean perception. Chicago: University of Chicago Press.

Kovács, I., Papathomas, T., Yang, M., Feher, A. (1996). When the brain changes its mind: Interocular grouping during binocular rivalry. *Proceedings of the National Academy of the Sciences, USA*, 93, 15508-15511.

Logothetis, N. Leopold, D., Sheinberg, D. (1996) What is rivalling during binocular rivalry? *Nature*, 380, 621-624.

McAnany, J. J., & Levine, M. W. (2002). The Vanishing Disk; a Revealing Quirk of the Scintillating Grid Illusion. *Journal of Vision*, 2(7), 204a, <http://journalofvision.org/2/7/204/>, doi:10.1167/2.7.204.

McAnany, J. J., & Levine, M. W. (2003). The blanking phenomenon and its psychoanatomical implications. *Journal of Vision*, 3(9), 767a, <http://journalofvision.org/3/9/767/>, doi:10.1167/3.9.767.

McAnany, J., Levine, M. W. (2004). The blanking phenomenon: a novel form of visual disappearance. *Vision Research*. 44, 993-1001.

Moses R. A., Hart, W. M. (1987) Adler's Physiology of the eye, Clinical Application, 8th ed. St. Louis: The C. V. Mosby Company.

Ono H., Barbeito R. (1985) Utrocular discrimination is not sufficient for utrocular identification. *Vision Research*. 25, 289-99.

Schrauf, M., Lingelbach, B., & Wist, E. R. (1997). The scintillating grid illusion. *Vision Research*, 37, 1033–1038.

Spillman, L. (1994). The Hermann grid illusion: a tool for studying human perspective field organization. *Perception*, 23(6), 691-708.

Treutwein, B. (1995). Adaptive psychophysical procedures. *Vision Research*, 35, 2503-2522.

Figure Captions

Figure 1: Demonstration of the blanking phenomenon and stimulus dimensions. The disk appeared 18.15 degrees above or below fixation, and the disk could be darker or lighter than the background alley-gray. Both arrangements are depicted simultaneously in this schematic, but during a trial only the upper or lower configuration (4 columns x 2 rows, and a single disk) was presented.

Figure 2: Stereoscope. The mirror stereoscope is depicted in Figure 2A. Figure 2B shows the fixation target employed in all experiments. The reader with stereovision can fuse the fixation targets to gain an appreciation of the appearance of the fixation target used in the experiments.

Figure 3: Stimuli for experiment I. The reader with stereovision can fuse the left and right images.

Figure 4: Results of experiment I. Contrast threshold for each subject is given for each condition by the appropriate bar indicated by the key. Error bars represent 95% confidence intervals; lack of error bars indicates stimuli that could not be seen at the maximum available contrast. The maximum available contrast for Subject 1 was different from Subjects 2 and 3 due to the difference in background alley-gray (see text for details).

Figure 5: Stimuli for experiment II. The opposite polarity condition is shown in 5A and the same polarity condition is shown in 5B.

Figure 6: Results of experiment II showing the contrast threshold for each subject for the same- (stippled bars) and opposite-polarity (striped bars) conditions. Black bars represent complementary disks presented in the absence of squares. Error bars represent 95% confidence intervals. The absence of error bars on bars for the opposite-polarity condition indicates that the disks were never visible and variance was zero.

Figure 7: Stimuli for experiment III. The disparity condition is shown in 7A and the offset condition is shown in 7B.

Figure 8: Results of experiment III showing the contrast threshold for each subject for the disparity (stippled bars) and offset (gray bars) conditions. Error bars represent 95% confidence intervals.

Figure 9: Slope of the staircase as an indication of binocular rivalry. Four simulated staircases obtained using the simulated rivalry method are depicted in 9A (see text). Staircases obtained from a condition in which maximal blanking was present are depicted in 9B. Typical staircases from experiment I are shown in the bottom panel (9C).

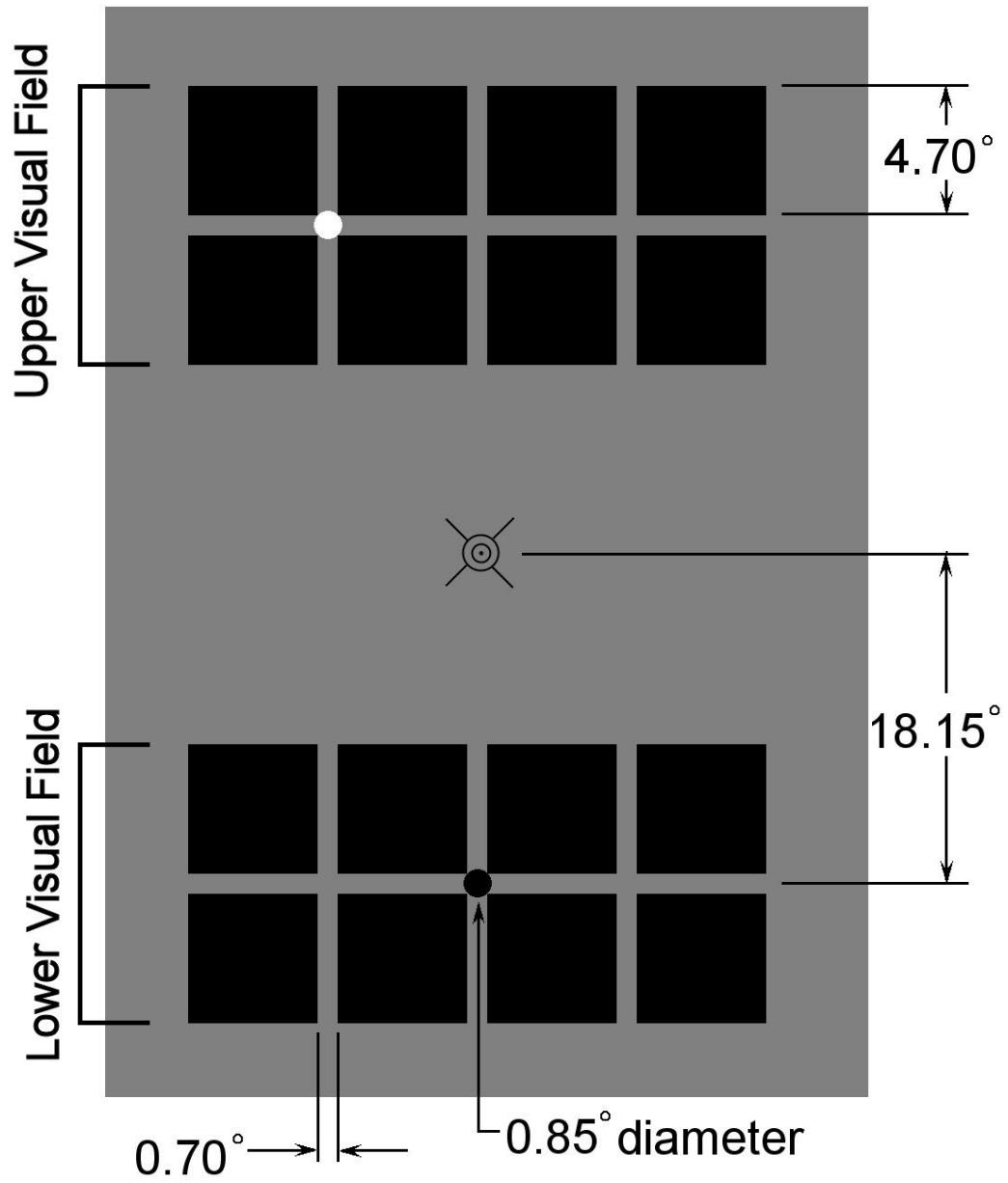
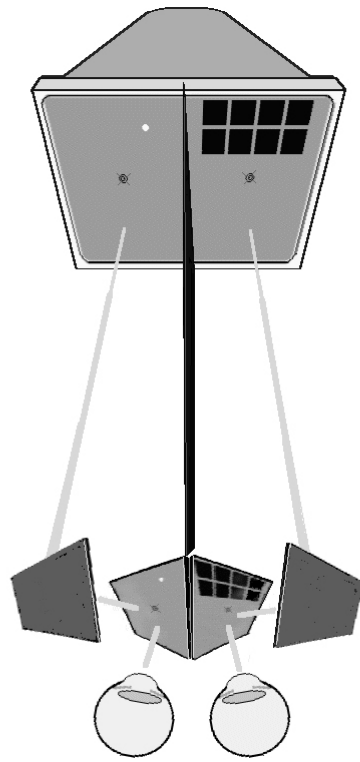
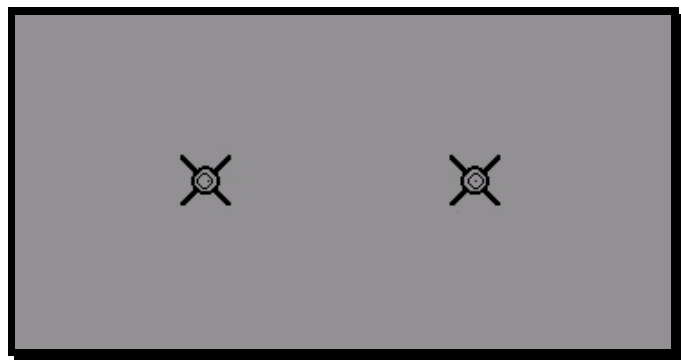


Figure 1



A



B

Figure 2

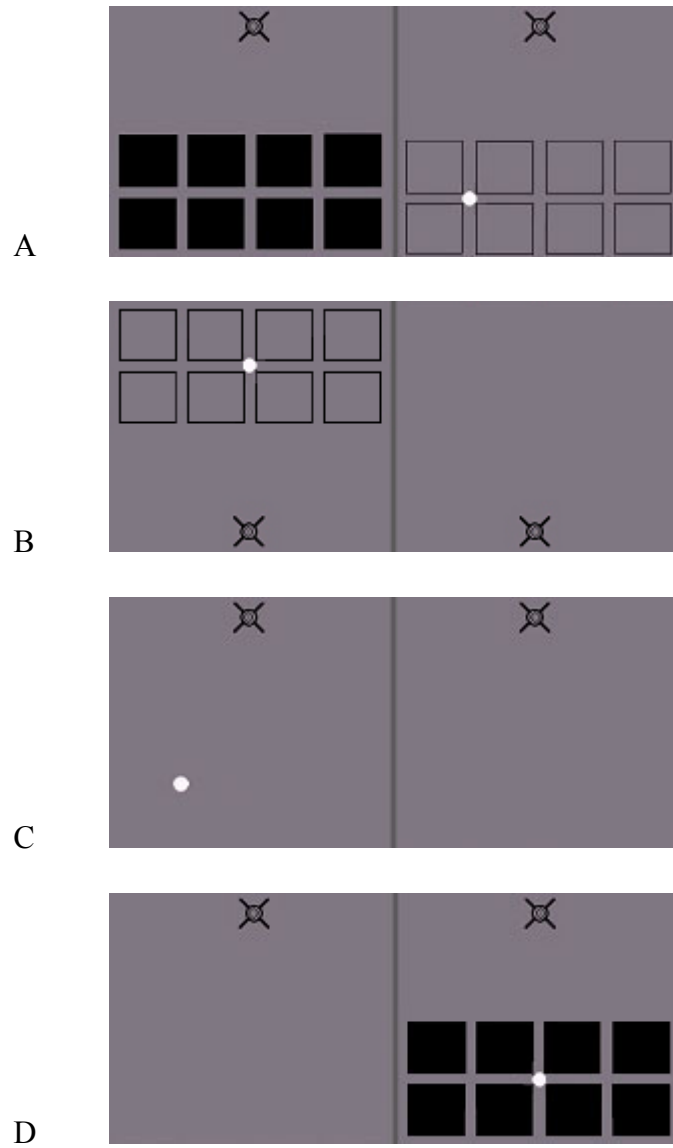


Figure 3

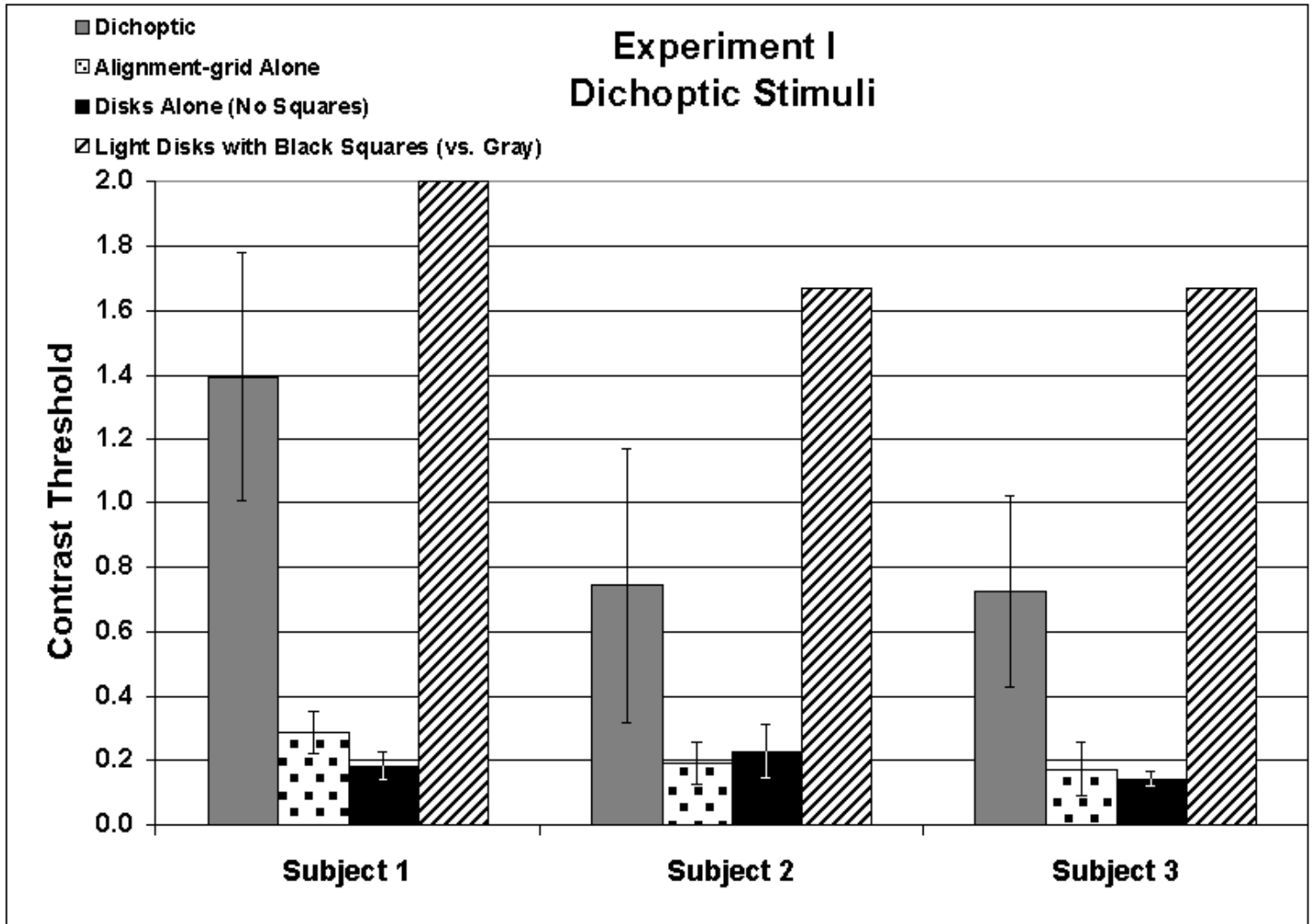


Figure 4

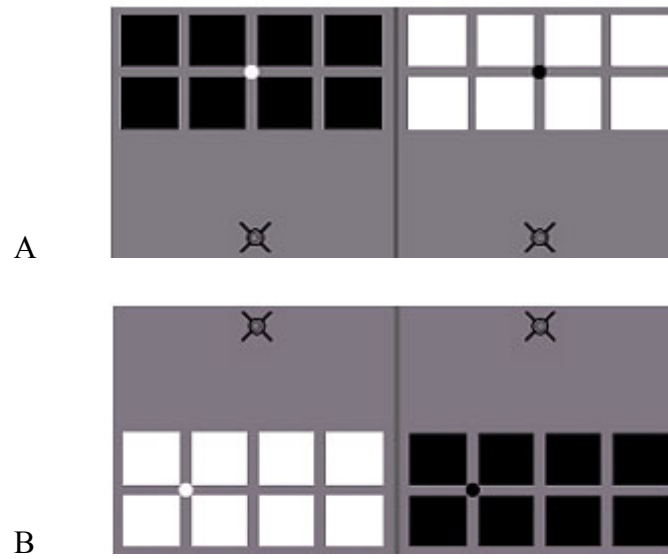


Figure 5

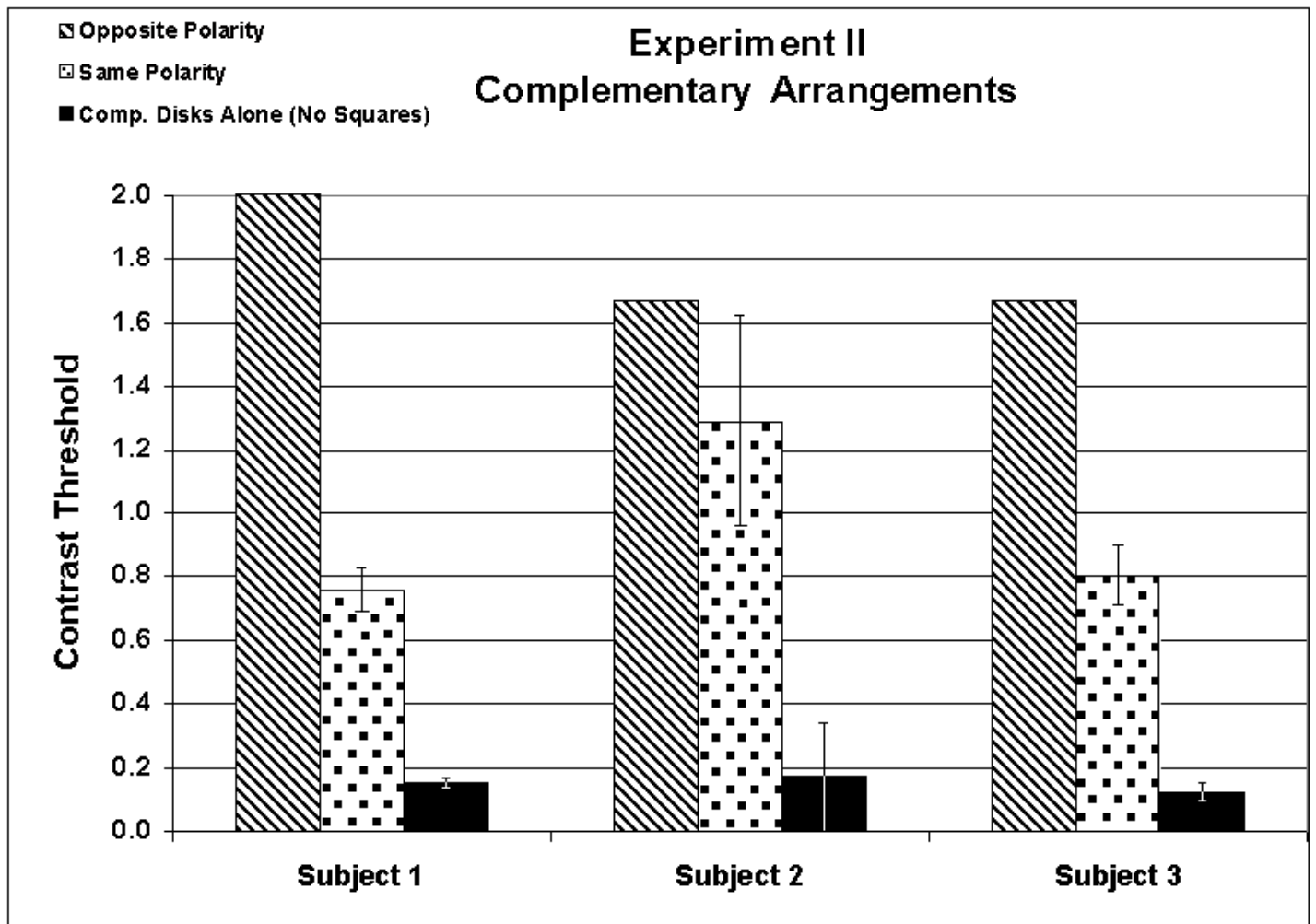


Figure 6

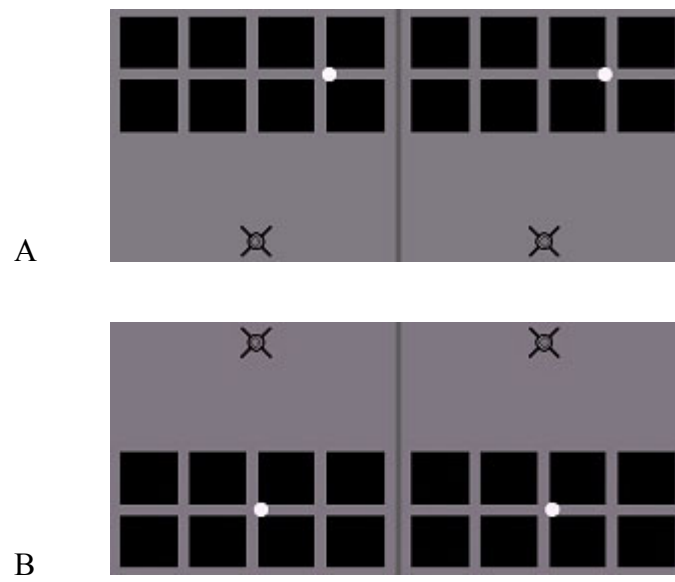


Figure 7

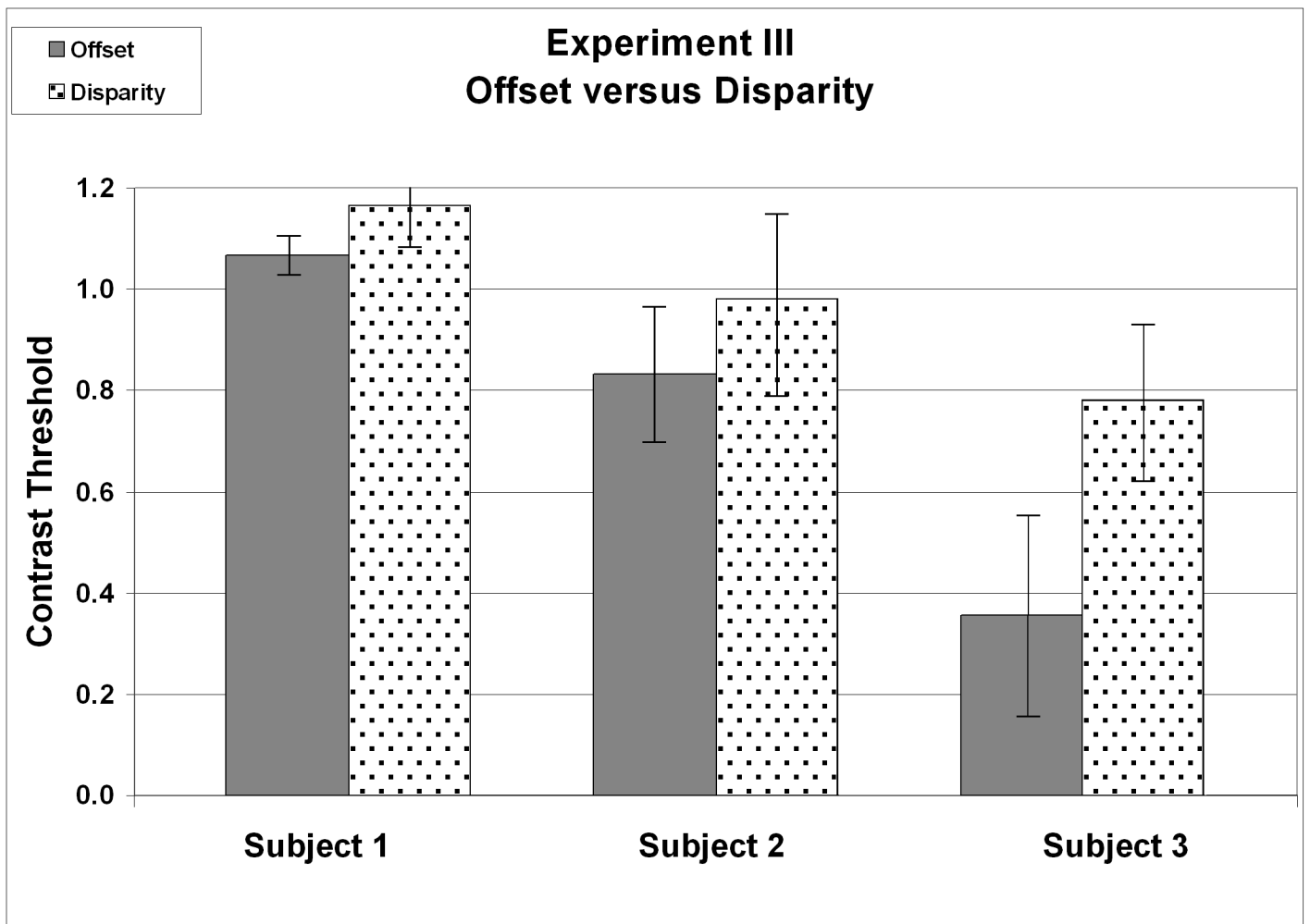


Figure 8

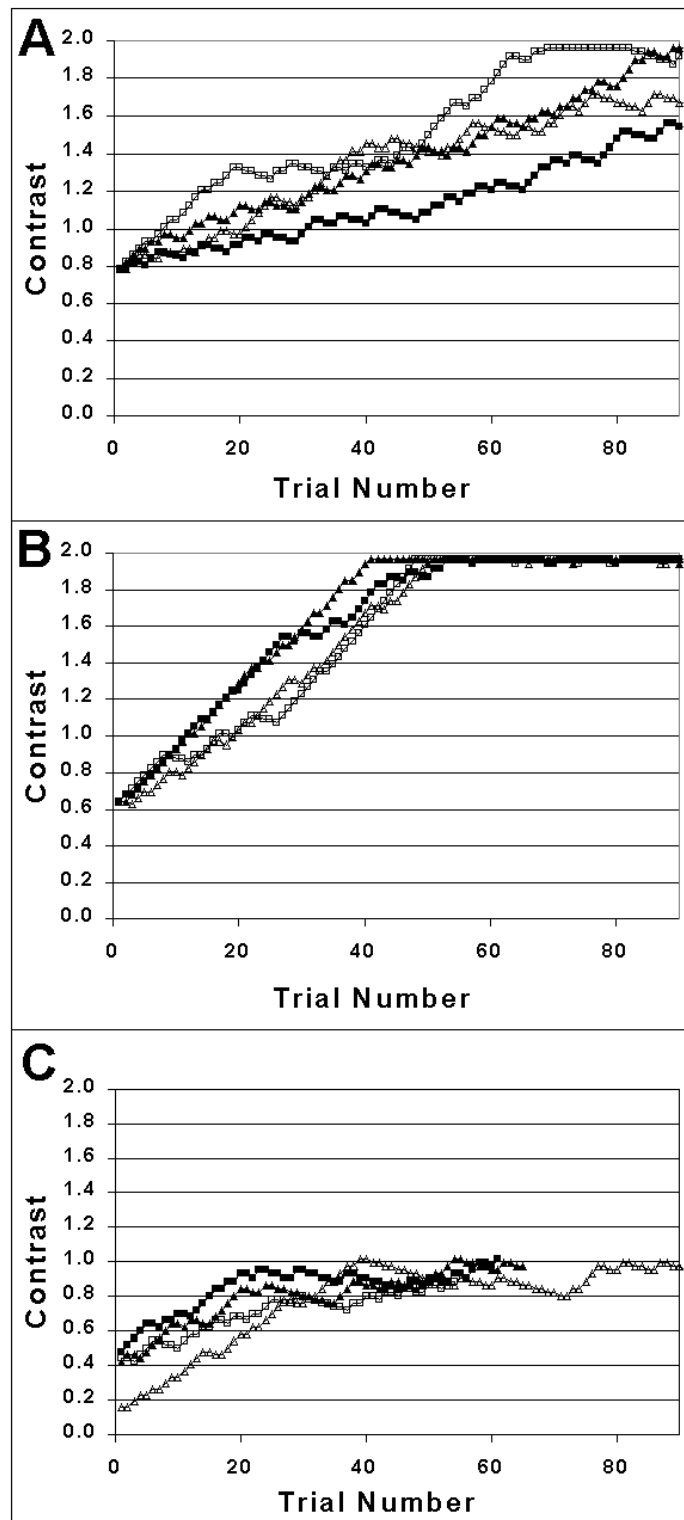


Figure 9