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Moving phantom visibility as a function of fundus pigmentation

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Moving phantom visibility was measured for subjects with a fundus classified as either lightly or darkly pigmented. The phantom-inducing pattern was a black-and-white square-wave grating drifting continuously from left to right, with a black horizontal occluder interrupting the middle of the grating. Moving phantom visibility was significantly reduced for darker relative to lighter pigmented subjects. The results show that fundus pigmentation can influence the perception of illusory contours and surfaces (i.e., phantoms). This finding supports and expands on previous research concerning fundus pigmentation influences on real contour perception.

Visual phantoms have been described as a figure-ground reversible illusion (Brown, 1985; Brown & Weisstein, 1988). A typical phantom-inducing pattern is a vertical black-and-white square-wave grating drifting continuously from left to right, with a black horizontal occluder blocking out the center portion of the grating. When phantoms are not visible, the occluder often appears in front of the moving grating stripes, blocking them from view. When phantoms are perceived, the occluder and black grating stripes undergo a figure-ground reversal, with the occluder appearing behind the now complete black grating stripes that move along in front of it. Phantoms, therefore, involve the perception of contours and surfaces that are not physically present when the observer organizes the stimulus in a particular way. The phantom illusion has been used to explore figure-ground processing (Brown & Weisstein, 1988) and perceptual organization (Brown & Weisstein, 1991).

During earlier phantom research (Brown, 1985), subjects were screened at the beginning of the experiment to determine if they saw phantoms before continuing in the experiment. Subjects viewed a standard moving phantom-inducing display and repeatedly described what they saw. The subjects eventually describing an organization of the display indicating that they were seeing phantoms were then informed of the illusory nature of that organization, the name of the illusion, and so forth. Of the many subjects screened this way, some never reported seeing an organization that indicated that they saw phantoms, even after they were finally told about the illusion and what to look for. It was noted at the time that most of these subjects were African-Americans. Considering skin pigmentation is a predictor of fundus density/darkness (Silvar & Pollack, 1967), and that under some conditions fundus pigmentation has been shown to have perceptual consequences (e.g., see below), it was hypothesized that fundus pigmentation may have an influence on whether or not phantoms are seen.

Previous studies investigating the relationship between fundus pigmentation and perceptual processing have included tests of Müller-Lyer illusion magnitude (Berry, 1971; Ebert & Pollack, 1972a, 1972b, 1973; Jahoda, 1971; Pollack & Silvar, 1967), WISC block-design subtest performance (Mitchell & Pollack, 1974; Mitchell, Pollack, & McGrew, 1977), and a spatial-geographical test (Jahoda, 1971). Fundus pigmentation has been shown to influence the magnitude of the Müller-Lyer illusion for both children (Berry, 1971; Pollack & Silvar, 1967) and adults (Berry, 1971; Ebert & Pollack, 1972a, 1972b, 1973; Jahoda, 1971). Some studies compared white with nonwhite observers (Berry, 1971; Jahoda, 1971; Pollack & Silvar, 1967), whereas others compared white observers classified as lightly or darkly pigmented according to fundus readings (Ebert & Pollack, 1972a, 1972b, 1973). In general, observers with relatively darker pigmentation exhibited a smaller illusion magnitude than did those with relatively lighter pigmentation. The results suggest that a darker pigmentation affects real contour processing by decreasing sensitivity to contrast.

Other studies examining the influence of fundus pigmentation on form perception have measured WISC block-design subtest performance by using both red/white and blue/yellow blocks under normal (Mitchell & Pollack, 1974; Mitchell et al., 1977) and reduced (Mitchell et al., 1977) lighting conditions. This visuocognitive task requires interpretation of contour orientation and spacing from a two-dimensional pattern and re-creating the pattern by manipulating the exposed side of identical two-colored blocks. Performance was poorer for darkly pigmented observers than it was for lightly pigmented observers across both lighting conditions and poorest for darkly pigmented observers under reduced lighting tested with blue/yellow blocks.

Finally, Jahoda (1971) examined the influence of fundus pigmentation on a spatial-geographical task. The task involved experienced geography students who made judg-

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ments about cross-profiles of land height or water depth from shading gradients. The gradients consisted of changes in the lightness of yellow/red to indicate height and changes in the lightness of purple/blue to indicate depth. Immediately after viewing a briefly presented shading gradient, subjects made a four-alternative forced choice of the appropriate corresponding black-and-white cross-profile. Darkly pigmented performance was below lightly pigmented performance for both height and depth judgments. Performance was poorest for darkly pigmented observers in the water (purple/blue) condition.

The combined results from these three different perceptual tasks suggest that fundus pigmentation may influence sensitivity to both lightness and hue contrast and that these differences in sensitivity may have effects on contour, form, and depth perception. If differences in pigmentation can influence contour, form and depth perception, would there be a systematic effect of fundus pigmentation on moving visual phantoms, a figure-ground illusion that involves contour, form, and depth perception? The observation noted above suggests that there might be. If contour, form, and depth perception are affected negatively by an observer having a relatively darker fundus, then phantom perception would be expected to be affected negatively as well. In addition, previous phantom studies have shown inducing-grating contrast does not significantly affect phantom visibility (Genter & Weisstein, 1981; Tynan & Sekuler, 1975). In fact, as long as the inducing grating is just above detection threshold, phantoms are visible (Genter & Weisstein, 1981; Mulvanny, Macarthur, & Sekuler, 1982; Tynan & Sekuler, 1975). However, these studies most likely used predominantly lightly pigmented observers. If the differences between lightly and darkly pigmented observers in contour, form, and depth perception are due to differences in contrast sensitivity, then phantom-inducing grating contrast may have an effect on phantom visibility for darkly pigmented observers but have no effect on lightly pigmented observers. The following experiment tested for differences in phantom visibility as a function of fundus pigmentation and inducing grating contrast.

METHOD

Subjects

Thirty-two introductory psychology students participated for course credit. All subjects had normal or corrected-to-normal vision and normal color vision.

Stimulus and Apparatus

Stimuli were created and presented with a computer-controlled Data Translation 2862 Frame Grabber output to an NEC DM-2000P monitor. The phantom-inducing pattern was a 0.75 cpd black-and-white square-wave grating drifting continuously from left to right at 0.78 deg/sec. The grating subtended 1.26° (h) × 10.79° (w) visual angle above and below a 0.66° (h) × 10.79° (w) black horizontal occluder. The mean screen luminance was 6.8 cd/m^2 with the grating presented at five different contrast levels (0.38, 0.48, 0.68, 0.88, 0.95). Viewing was monocular from a chinrest.

Measures of fundus reflectance were taken just to the left of the foveal depression by using a Photovolt light meter connected to one eyepiece of a Bausch and Lomb binocular ophthalmoscope. A scale of reflectance was derived from the photometric scale (see Youn & Pollack, 1989). The range of reflectance varied from 1 unit, indicating dense or dark pigment, to 21 units, indicating a greater reflectance or light pigment. Each unit represents a photometric value of 5×10^{-7} footcandle. The subjects were divided into two groups according to their fundus pigmentation readings. The mean fundus pigment reading (based on the 21-point scale) across all subjects was 9.01. The 15 subjects above the mean were grouped together as lightly pigmented, and the remaining 17 below the mean made up the darkly pigmented group. The mean fundus pigment readings ($\pm SD$) for light- and dark-pigment subjects were 12.58 ± 3.64 and 5.87 ± 2.25, respectively. The lightly pigmented group consisted of 14 Caucasians and 1 African-American. The darkly pigmented group consisted of 9 African-Americans, 4 Caucasians, two Japanese-Americans, and 1 Jamaican.

Procedure

The subjects were first introduced to visual-completion illusions by being shown a piece of paper with two Kanizsa triangles (Kanizsa, 1979), a black version (white inducing elements) and a white version (black inducing elements) on one half, and a schematic of a black-and-white phantom inducing pattern on the other half. The illusory nature of the triangle surfaces and edges were discussed and pointed out by covering the inducing elements. The subjects were then informed that the present experiment concerned visual phantoms—that is, another illusion in which contours and surfaces are seen but are not physically present. A stationary pattern on the TV screen and the schematic illustration on paper were used in describing the phantom illusion. The subjects were told that when the black vertical stripes are made to move continuously from left to right, they might appear to be complete from top to bottom in front of the black horizontal region. If and when the inducing pattern appeared this way, the subjects would be seeing phantoms. The fluctuating, subjective nature of phantoms (unlike the illusory triangles, which always remain visible) was also discussed.

The subjects were then told that the viewing conditions (e.g., room lighting and the observer's state of dark adaptation) can affect phantom visibility, resulting in their being dark-adapted for 5 min before continuing. After dark-adapting, the subjects viewed a stationary inducing pattern at each of the five contrast levels and adjusted the brightness of the fixation point to be just visible at each level. The subjects were instructed to keep their gaze centered on the fixation point during the experiment to help keep their eyes from drifting with the moving inducing pattern.

The subjects viewed the inducing pattern four times at each of five contrast levels in 20 randomly presented 1-min trials. Phantom strength (percentage of total viewing time that phantoms were reported) and incubation time (time elapsed on each trial before phantoms were first reported) were measured by having the subjects press and hold down the spacebar key on the computer keyboard any time phantoms were visible.

RESULTS

Moving phantoms were visible significantly more often for lightly than for darkly pigmented subjects (see Figure 1). A 2 (light or dark fundus pigmentation) × 5 (contrast level) repeated measures analysis of variance (ANOVA) on phantom strength was significant only for the main effect of fundus pigmentation [$F(1,30) = 20.40$, $p < .0001$]. Because darkly pigmented observers may be less sensitive to contrast, it was expected that they would be the most affected by contrast. Therefore, separate one-way repeated-measures ANOVAs assessing

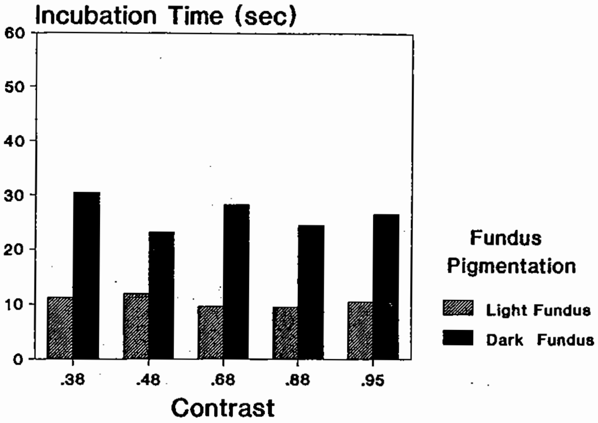

Figure 1. Phantom strength (i.e., the percentage of total viewing time in which phantoms were visible) as a function of inducing grating contrast and fundus pigmentation.

phantom visibility across contrast levels for lightly and darkly pigmented observers were made. A significant effect of contrast was found only for the darkly pigmented group [$F(4,64) = 2.57$, $p < .03$]. A Tukey multiple-comparison test showed that the 0.38 and 0.95 contrast conditions were significantly different ($p < .05$). Although lightly pigmented observers saw phantoms more often than did darkly pigmented observers, phantom visibility was not affected by contrast. Darkly pigmented observers did not see phantoms very often, but the highest contrast condition (0.95) did produce greater phantom visibility than did the lowest (0.38) contrast condition.

A 2 (light or dark fundus pigmentation) × 5 (contrast level) repeated measures ANOVA on incubation time was significant only for the main effect of fundus pigmentation [$F(1,30) = 7.63$, $p < .009$]. Separate one-way ANOVAs were also nonsignificant. The results show that incubation time was significantly longer for darkly than for lightly pigmented observers (see Figure 2).

Product-moment correlations between fundus-pigmentation reading and phantom visibility were calculated for phantom visibility averaged across all contrast levels, and for phantom visibility at each contrast level separately. Fundus pigmentation correlated significantly with phantom visibility when visibility was averaged across all contrast levels [$r(30) = .61, p < .0001$], as well as when it was calculated for each contrast level separately [Level 1, $r(30) = .48$, $p < .003$; Level 2, $r(30) = .53$, $p < .0009$; Level 3, $r(30) = .66$, $p < .00001$; Level 4, $r(30) = .54$, $p < .0007$; Level 5, $r(30) = .49$, $p < .002$]. These results indicate that as fundus-pigmentation readings decreased, phantom visibility decreased also, and that this relationship held across all contrast levels tested. In other words, the darker the observer's pigmentation, the less likely the observer was to report seeing the phantom illusion.

Product-moment correlations between fundus pigmentation readings and incubation time were also calculated for incubation time averaged across all contrast levels and for incubation time at each contrast level separately. Fundus pigmentation correlated significantly with incubation time when visibility was averaged across all contrast levels [$r(30) = -.42, p < .008$], as well as when it was calculated for each contrast level separately [Level 1, $r(30) = -.44$, $p < .006$; Level 2, $r(30) = -.29$, $p < .05$; Level 3, $r(30) = -.44$, $p < .006$; Level 4, $r(30) = -.37, p < .01$; Level 5, $r(30) = -.40, p < .01$]. These results, together with the phantom visibility results, indicate that the darker the observers' pigmentation, the less likely they were to see the phantom illusion and the longer it took them to begin to see the illusion when they did see it.

DISCUSSION

The phantom illusion involves the perception of contours and surfaces that are not physically present. It took longer to begin seeing these illusory contours and surfaces, and they were visible significantly less often for the darkly pigmented than for the lightly pigmented observers. Previous findings showing that fundus pigmentation can have perceptual consequences have used three completely different visual tasks that all involved the perception of real contours. Even the Müller-Lyer illusion involved making comparative judgments of line length on the basis of the perception of achromatic (Ebert & Pollack, 1972b, 1973; Pollack & Silvar, 1967) or chromatic (Berry, 1971; Ebert & Pollack, 1972a) real contours. Why should a difference in fundus affect the visibility of these illusory contours and surfaces? Before trying to answer this question, we should ask, what is the difference between a lightly and a darkly pigmented fundus?

Our fundus measurements were made using the broad-spectrum wavelengths of a tungsten lamp with a peak of between 650 and 700 nm. For these peak wavelengths, the differences in fundus readings were most likely a reflection of choroidal melanin concentration (Hunold &

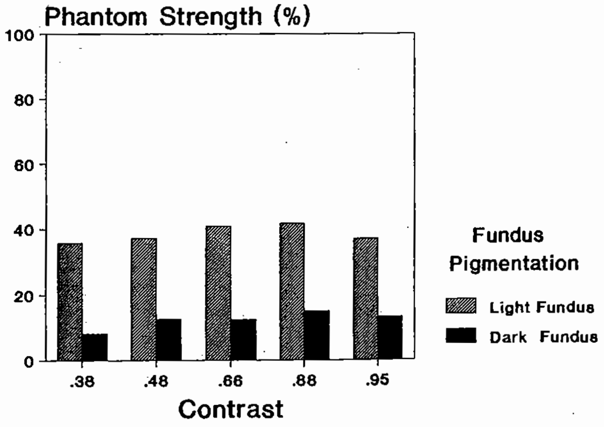

Figure 2. Incubation time (i.e., time elapsed in each trial before phantoms were first reported) as a function of inducing grating contrast and fundus pigmentation.

Malessa, 1974; Weiter, Delori, Wing, & Fitch, 1986). Differences in choroidal melanin concentration have been found when comparing blacks and whites for both foveal (Hunold & Malessa, 1974; Weiter et al., 1986) and peripheral regions (Weiter et al., 1986). In our measurements, higher choroidal melanin concentrations would have led to less reflected light, leading to a lower photometric reading and thus to classification of darkly pigmented. Therefore, our subjects were classified as having a darkly or lightly pigmented fundus on the basis of these readings and not on the basis of race. Ebert & Pollack (1972a, 1972b, 1973) used the same fundus measurement device with white observers only. They were able to divide observers into groups on the basis of fundus measurements that apparently reflected differences in choroidal melanin concentration also. It appears, then, that when differences are found in choroidal melanin concentration between groups, regardless of race, measurable perceptual consequences may be found.

What is it about choroidal melanin concentration that would lead to differences in the perception of real and illusory contours? One possibility might be that a darker fundus (i.e., a higher choroidal melanin concentration) reduces the amount of light reflected off the back of the eye. If we assume for the moment that less reflected light or light scatter would lead to greater visual acuity, would this account for the effects of fundus pigmentation on performance that have been found for these different perceptual tasks? The most glaring example counter to this hypothesis is the difference in WISC block-design performance. We can think of no reason why greater visual acuity would make it more difficult to perform this task.

What about the present phantom results—could they be accounted for by darkly pigmented observers having less light scatter? If less reflected light leads to greater acuity, then it might make sense that the perception of illusory contours and surfaces would be reduced. However, this hypothesis must be rejected for two reasons. First, the data do not support the hypothesis. The correlations between measured acuity and fundus measurement, and between measured acuity and phantom visibility, were not significant. Second, if the phantom illusion were a stray-light phenomenon, then it should follow that increasing or decreasing stray light would lead to an increase or decrease in phantom visibility, respectively. However, previous research has shown that the phantom illusion is not a stray-light phenomenon, for a number of reasons. For example, moving (Tynan & Sekuler, 1975), flickering (Genter & Weisstein, 1981), and stationary (Gyoba, 1983) phantoms are seen dichoptically—that is, when the top half of the inducing grating and occluder is presented to one eye and the bottom half is presented to the other eye. The illusion is not found when either half is seen alone. This suggests that the phantom illusion may originate somewhere in the visual system beyond the point where information from the two eyes is combined (Genter & Weisstein, 1981; Gyoba, 1983; Tynan & Sekuler, 1975). Also, as mentioned earlier, phantoms are visible when the contrast of the inducing grating is only slightly above "real" grating threshold (Genter & Weisstein, 1981; Mulvanny et al., 1982; Tynan & Sekuler, 1975). In fact, it has been reported that "phantom gratings often appeared more vivid when induced by a low-contrast grating than when induced by a higher-contrast grating" (Tynan & Sekuler, 1975, p. 952), an observation in complete opposition to a light scatter explanation of phantoms. Similarly, if phantoms were a stray-light phenomenon, then increasing the distance across which the light must scatter (i.e., the occluder height) would be expected to decrease phantom visibility, but this proves not to be the case. Phantoms are visible across a large range of occluder heights, in some cases where the occluder takes up 80% (Genter & Weisstein, 1981) to 82% (Tynan & Sekuler, 1975) of the display. As Tynan & Sekuler (1975) point out, "it is unlikely that internally scattered light would be of sufficient intensity and spatial extent to produce vivid entopic gratings" (p. 952). Finally, phantom completion involves the perception of a definite shape "corresponding to the shape of the inducing object" (Gyoba, 1983, p. 206), including stripes (Genter & Weisstein, 1981; Tynan & Sekuler, 1975), dots (Tynan & Sekuler, 1975), and columns of Xs (Weisstein & Maguire, 1978). All of these findings run counter to a stray-light account of the phantom illusion and, therefore, of the present differences in phantom visibility caused by fundus pigmentation.

If differences in fundus pigmentation (i.e., choroidal melanin concentration) lead to differences in perceptual processing, how might future studies probe these differences using either traditional psychophysical measures or phantoms as a tool? Considering that all of the experiments showing an influence of fundus pigmentation have been spatial tasks, one possibility currently being explored is whether fundus pigmentation may also influence temporal processing. We are looking at flickering phantom visibility as a function of flicker rate. Given the present results, darkly pigmented observers should show reduced phantom visibility relative to lightly pigmented observers, but the question is whether or not they will exhibit the same temporal tuning functions as do lightly pigmented observers. Another approach would be to consider how we might enhance performance for darkly pigmented observers or degrade performance for lightly pigmented observers to equate the two groups. For example, are the present differences in phantom visibility caused by a contrast mechanism that is sensitive to the particular level of illumination (or observer adaptation)? In other words, is there a contrast threshold above which phantoms are easily seen and below which they are rarely seen? If so, then increasing the overall illumination above our relatively low level (6.8 cd/m^2) might push those with a darker fundus over the contrast threshold and increase phantom visibility, while visibility for those with a lighter fundus either decreases or remains unchanged. Another potential source of information may be to measure phantom visibility by using colored inducing gratings. This would be useful for two reasons. First, we could examine differences in phantom visibility for lightly and darkly pigmented viewers as a function of wavelength; second, it would allow for the creation of equiluminant inducing gratings and the possibility of equiluminant phantoms. If there are differences in sensitivity to real chromatic and achromatic contour contrast caused by fundus pigmentation, as previously suggested, then equiluminant inducing displays might offer further insight into these differences. For example, if there were no differences in equiluminant phantom visibility as a function of fundus pigmentation, then the differences found in this study would more likely be due to magnocellular-pathway-mediated contrast mechanisms. Finally, considering the suggested differences in sensitivity to real contour contrast relative to fundus pigmentation, it may be informative to examine and compare the contrast sensitivity functions of lightly and darkly pigmented individuals. Future studies examining these and other issues will be needed to further delineate the mechanisms and processes contributing to the relationship between fundus pigmentation and perception.

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