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Linking motion-induced blindness to perceptual filling-in ☆

Li-Chuan Hsu, Su-Ling Yeh *, Peter Kramer

Department of Psychology, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd., Taipei 106, Taiwan

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Abstract

"Motion-induced blindness" and "perceptual filing-in" are two phenomena in which perceptually salient stimuli repeatedly disappear and reappear after prolonged viewing. Despite the many similarities between MIB and PFI, two differences suggest that they could be unrelated phenomena: (1) An area surrounded by background stimuli can be perceived to disappear completely in PFI but not in MIB and (2) high contrast stimuli are perceived to disappear less easily in PFI but, remarkably enough, more easily in MIB. In this article we show that the apparent differences between MIB and PFI disappear when eccentricity, contrast, and perceptual grouping are taken into account and that both are most likely caused by the same underlying mechanism.

Keywords: Motion; Filling-in; Adaptation; Contrast; Luminance; Perceptual grouping

1. Introduction

A typical "motion-induced blindness" (MIB) display (Fig. 1A) consists of three relatively small yellow dots presented near the fovea on a black background containing coherently moving blue random dots (Bonneh, Cooperman, & Sagi, 2001). After prolonged viewing, one or more of the yellow dots is repeatedly perceived to fade away and reappear for several seconds at a time. The yellow dots are surrounded by black annuli that, while not salient, are nevertheless not perceived to disappear. They seem to act like protective rings, free from the invasion of the blue background dots. Whereas a typical MIB display consists of yellow dots surrounded by black annuli in a field of blue dots, there are many variations on this display that also produce MIB. For ease of reference, we will therefore use more abstract terms and refer to the yellow dots as *targets*, to the annuli surrounding these targets as *surrounding zones* and to the blue background dots as *distracters*.

A typical "perceptual filling-in" (PFI) display (Fig. 1B) consists of one relatively large gray square that is presented peripherally on a dynamic noise background of black and white random dots (Anstis, 1989; Anstis, 1996; Ramachandran & Gregory, 1991; Ramachandran, Gregory, & Aiken, 1993; Spillmann & Kurtenbach, 1992). After prolonged viewing, the square is repeatedly perceived to fade away and reappear for periods of several seconds at a time, showing the same kind of behavior that the targets in MIB exhibit. Whereas a typical PFI display consists of a relatively large gray square and relatively small black and white random dots, there are many variations on this display as well that also produce PFI (Ramachandran & Gregory, 1991; Welchman & Harris, 2000, 2001). For ease of reference, we will also use the more abstract terms here and refer to the gray square as *target* and to the black and white dots as *distracters*.

MIB and PFI displays differ in a number of ways: (1) MIB-displays contain several targets, but PFI-displays, only one, (2) MIB-displays contain surrounding zones

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* Corresponding author. Tel.: +886 223663097; fax: +886 223629909.
E-mail address: suling@ntu.edu.tw (S.-L. Yeh).

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(A)

(B)

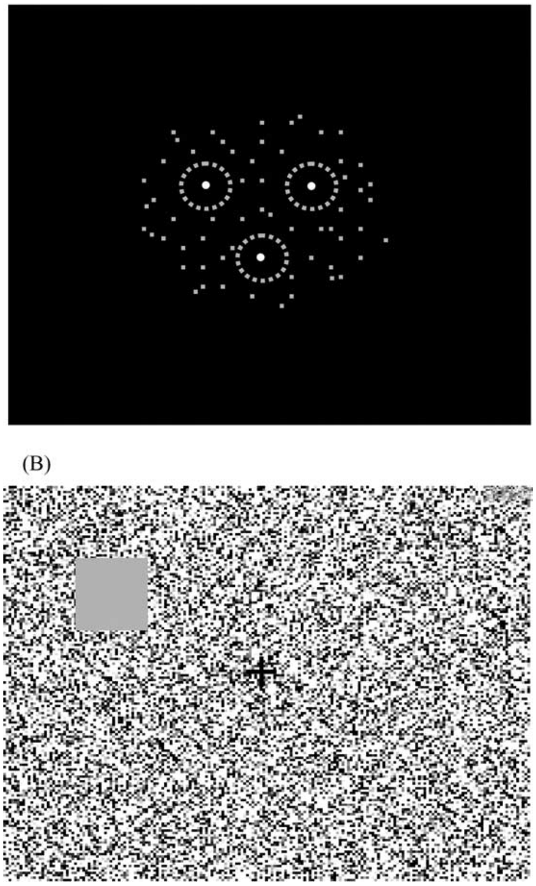

Fig. 1. (A) A typical MIB-display, with three yellow dots as targets (shown here in white), three non-salient black zones around these targets (here indicated by white dotted lines that were not shown to the participants) and a number of sparsely distributed blue random dots as distracters (shown here in dark gray) on a black background. The zones surrounding the targets are not salient when the distracters are stationary but are slightly more salient when the distracters are moving. (B) A typical PFI-display, with a gray square as a target and high-density black and white dots as distracters.

around the target, but PFI-displays do not, (3) the dot-density of the background pattern is low in MIB-displays but high in PFI-displays (although cf. Welchman & Harris, 2000), (4) the distracters are usually moving coherently in MIB-displays, but incoherently in PFI displays, although MIB and PFI can both be observed in completely static displays (Bonneh et al., 2001; Ramachandran & Gregory, 1991; Ramachandran et al., 1993; Spillmann & Kurtenbach, 1992; Welchman & Harris, 2000, 2001) and MIB has also been induced with the help of incoherent motion (Leopold, Wilke, Maier, & Logothetis, 2002), (5) targets are presented close to the fovea in MIB displays but further into the periphery in PFI displays (De Weerd, Desimone, & Ungerleider, 1998; De Weerd, Gattass, Desimone, & Ungerleider, 1995; Ramachandran et al., 1993; Welchman & Harris, 2001), and (6) the colors used in MIB and PFI displays are different, typically yellow and blue in MIB-PFI-displays.

Whereas there are several differences between MIB- and PFI-displays, the MIB and PFI phenomena themselves seem very similar: In both, salient stimuli are repeatedly perceived to disappear for several seconds, both are best induced by backgrounds that contain motion, and both have been shown to be more complex than mere retinal suppression or adaptation (De Weerd et al., 1998; Ramachandran & Gregory, 1991; Ramachandran et al., 1993; Spillmann & Kurtenbach, 1992; Troxler, 1804). There are two differences, however, that suggest that MIB and PFI, despite their similarities, may nevertheless be categorically different phenomena.

The first difference concerns the extent to which stimuli are perceived to fade away. In MIB, on the one hand, relatively small targets are perceived to disappear, but relatively large zones surrounding these targets are not. In PFI, on the other hand, relatively large targets are perceived to disappear completely. The targets, however, are presented further into the periphery in PFI-displays than in MIB-displays (although cf. De Weerd et al., 1998; Welchman & Harris, 2001). In Experiment 1, we test whether the zones surrounding the targets in MIB displays can be perceived to fade away too, at greater eccentricities, or whether they are zones that are indeed protected from fading.

The second difference concerns a contrast effect. Whereas in PFI, high contrast targets are less easily perceived to disappear (Sakaguchi, 2001; Welchman & Harris, 2001), in MIB, contrary to expectations, they are actually more easily perceived to disappear. In Experiment 2, we examine to what extent MIB and PFI are differentially affected by contrast.

Bonneh et al. (2001) argued that it could be competition between targets and distracters that causes the perceived fading of the targets. However, if targets and distracters cannot be distinguished, then there can be no competition between them. This leads us to the hypothesis that the perceived fading of targets could be inversely related to the similarity between these targets and their distracters. Taking it one step further, we hypothesize that weak perceptual grouping between targets and distracters, in general, should lead to more perceived disappearance.

It so happens that targets and distracters never group well in PFI-displays because of a large size difference between them. In MIB displays, however, such grouping is possible, especially when the targets and distracters are similar in luminance. Thus, that the contrast of a target has a different effect on MIB than on PFI may be the result of perceptual grouping. Bonneh et al. (2001) have already shown that grouping among targets themselves affects their perceived fading. In Experiments 3 and 4, we will show that grouping between targets and distracters does so as well.

2. Methods

2.1. Observers

Four naïve observers and one author participated in Experiments 1 and 2, and three naïve observers and one author participated in Experiments 3 and 4. All had normal or corrected-to-normal vision.

2.2. Apparatus and stimuli

The stimuli were constructed and controlled by Presentation v0.47 software (Neural Behavior Systems Corporation), using an IBM compatible personal computer with a 17-inch calibrated EIZO color monitor that was viewed from a distance of 50 cm. All experiments had completely randomized within-subjects designs.

In order to test our hypotheses, we created new versions of the MIB-display (Fig. 2A) and the PFI-display (Fig. 2B) that facilitate comparisons between MIB and PFI in Experiments 1 and 2. The most important modification is that we introduced a small dot in the middle of the square that is typically used as a target in PFI-displays. Rather than the square, this small dot will now be referred to as the *target*, and that part of the square that surrounds this target will now be referred to as the *surrounding zone*. This small adjustment of the PFI-display has no major effect on the PFI observed, and we will show that we replicate earlier PFI-findings and that both the target and the surrounding zone can be perceived to disappear.

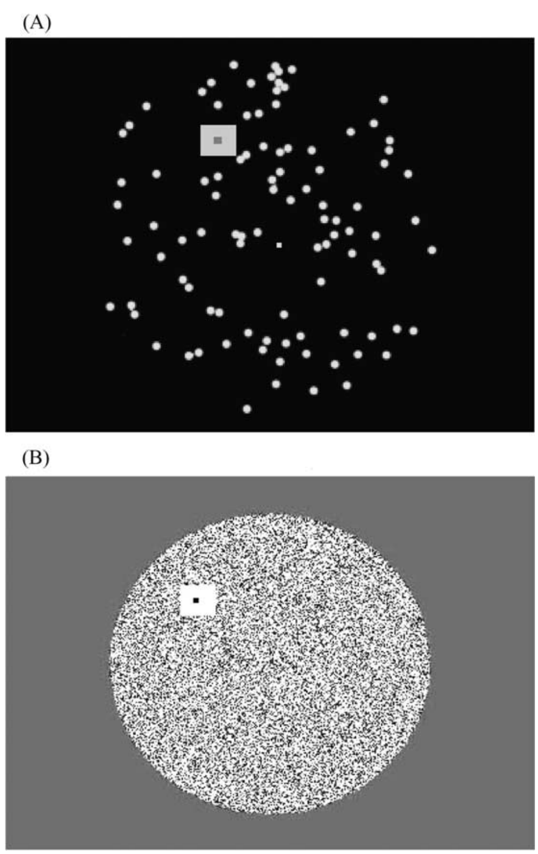

Fig. 2. (A) An MIB-display with one small square as a target (shown here in dark gray), a zone surrounding the target that normally has the same color as the background (for clarity shown here in light gray rather than black) and 1% blue random dots (shown here in white) on a black background. (B) A PFI-display with a small square as a target (shown here in black), a zone surrounding the target (here in white) and high-density black and white random dots as distracters.

In Experiment 1, a target ($0.23° \times 0.23°$ in size and with a luminance of 100 cd/m^2) was presented along with a surrounding zone ($2.7° \times 2.7°$ in size and with a luminance of 0.33 cd/m^2) on a black background (with a luminance of 0.10 cd/m^2). The background contained 100 sparsely distributed blue random dots (1%), 0.19° in diameter (5 pixels), with a luminance of 20 cd/m^2 and with a CIE of (0.151, 0.070). The mean luminance of the background and the dots together was 0.33 cd/m^2. The target was presented at distances of 1.2°, 2.4°, or 4.8° (center-to-center) from a red central fixation dot (CIE (0.602, 0.322), 0.19° in diameter, and with a luminance of 18 cd/m^2). Because eccentricity effects have already been observed in PFI (De Weerd et al., 1998; Ramachandran et al., 1993; Welchman & Harris, 2001), only MIB-displays were used in the first experiment.

Three background patterns, with a radius of 20.32°, were used: (1) dynamic random dots with a temporal frequency of 10 Hz (0% *coherent motion*) and with a random phase, which has been shown to be optimal for inducing PFI (Spillmann & Kurtenbach, 1992), (2) coherently moving dots that move in a clockwise circular direction, with a speed of 0.28 revolutions per second (100% *coherent motion condition*), and (3) static random dots (*static condition*). The experiment contained nine conditions, 3 background patterns $\times$ 3 eccentricities, and each condition consisted of 12 trials.

In Experiment 2, a target similar to that in Experiment 1 was presented along with a similar surrounding zone that was $1.66° \times 1.66°$ in size and that was located at an eccentricity of 5.90° in the upper left part of the screen. The surrounding zone was salient in some conditions (similar to the targets in typical PFI-displays) but much less salient in other conditions, in which it could have the same luminance as the background (consistent with typical MIB-displays). Backgrounds were either, as in Experiment 1, black with sparse blue random dots (commonly used in MIB-displays) or consisted of densely packed black and white random dots (commonly used in PFI-displays) which were 0.04° in diameter (1 pixel) and had a mean luminance of 50 cd/m^2 for the 50% black and 50% white dots together.

Contrast was manipulated in two different ways, for each of the blue random-dot backgrounds and the black-white random-dot backgrounds. When a sparse blue random dot on a black background was used, either (1) the luminance of the surrounding zone was kept at 0.33 cd/m^2, while that of the target was varied between 1, 5, 15, 45, 50, 60, and 70 cd/m^2, or (2) the luminance of the target was kept at 70 cd/m^2, while that of the surrounding zone was varied between 0.33, 5, 15, 45, 50, and 60 cd/m^2. The first contrast manipulation renders the zone surrounding the target not very salient (because it has the background color and luminance), and these displays are therefore similar to MIB-displays. The second contrast manipulation renders the zone surrounding the target salient for most luminance values, and these displays are therefore somewhat more similar to PFI-displays.

Similarly, when a black and white random-dot background was used, either (1) the luminance of the surrounding zone was held fixed at 50 cd/m^2, while that of the target was varied between 5, 15, 45, 60, and 70 cd/m^2, or (2) the luminance of the target dot was held fixed at 5 cd/m^2, while that of the surrounding zone was varied between 1, 15, 45, 50, 60, and 70 cd/m^2. In total, Experiment 2 contained 72 conditions, each with six trials.

In Experiments 3 and 4, MIB was induced with the help of four large blue crosses, $7.74° \times 7.74°$ in size, with a luminance of 20 cd/m^2 and a CIE of (0.151, 0.070) that rotated around their own axes at a speed of 0.28 revolutions per second. In Experiment 3, these large crosses were themselves composed of small crosses or small squares (Fig. 3). A yellow target, which would always appear at the center of the upper-left large cross and which could be different in shape from the distracters (Fig. 3A: poor perceptual grouping between target and distracters) or the same in shape (Fig. 3B: good perceptual grouping between target and distracters), was used. The target could be either a small yellow square or a small yellow cross, $2.1° \times 2.1°$ in size, with a luminance of 60 cd/m^2 and a CIE of (0.388, 0.514). It was presented at an eccentricity of 8.2° from a central fixation dot that

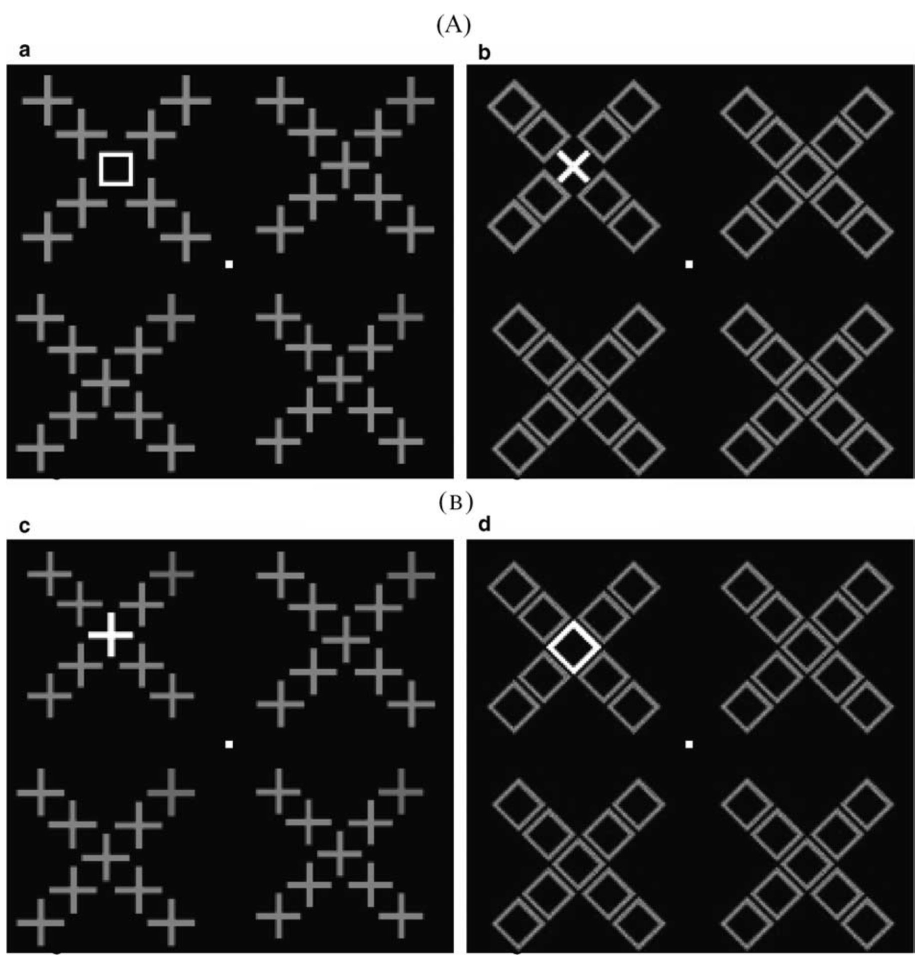

Fig. 3. MIB-displays with four large crosses, rotating around their own axes, consisting of blue distracters and, for the upper-left cross, a yellow target. The targets and distracters could be either dissimilar (A) or similar (B). Targets and fixation dots are shown here in white and the distracters in gray.

was similar to the one used in Experiments 1 and 2. Experiment 3 contained four conditions (Fig. 3), each with 10 trials.

Four large, coherently rotating crosses were also used in Experiment 4 (5.03° × 5.03° in size), but in this case, they consisted of small, blue disks (0.58° × 0.58°, Fig. 4) rather than crosses or squares. They moved at the same speed as in Experiment 3. The target was a yellow disk and was always stationary. In the *good continuation* condition (Fig. 4A), the target lined up well with the distracters. In the *poor continuation* condition (Fig. 4B), it did not line up and was placed away from the center of the cross. Both conditions were run for 10 trials each. To control for eccentricity effects, we displaced the upper-left cross in the *poor continuation* condition 2.78° to the left of the target so that the target appeared in the same location in both the *poor* and the *good continuation* conditions.

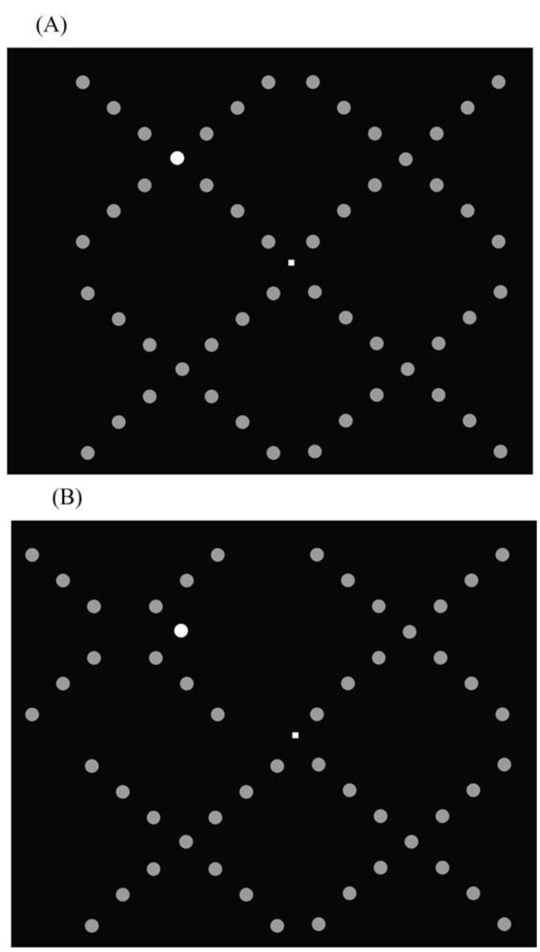

Fig. 4. MIB-displays with four large crosses, rotating around their own axes, consisting of blue distracters and, for the upper-left cross, a yellow target. The target remained stationary during the rotation of the crosses. The target and distracters could either show good continuation (A) or poor continuation (B). Targets and fixation dots are shown here in white and the distracters in gray.

2.3. Procedure

Several practice trials were performed to ensure that the observers understood their task properly. At the beginning of each trial (each of which lasted 1 min), the observers were requested to fixate on a red dot at the center of the display. They were asked to press the enter-key to start a stimulus presentation. To prevent fatigue, self-paced short breaks were allowed between the trials.

In Experiments 1 and 2, observers were asked to press the left-arrow key when the target was perceived to disappear and the right-arrow key when it appeared to reemerge. Both keys were controlled by the right hand. The left hand controlled the letter-A key, which was to be pressed when the zone surrounding the target was perceived to fade. Observers were informed that when the surrounding zone was dark and was not salient, they could nevertheless treat this apparently empty zone as the surrounding zone. Distracters were never presented in this zone. If observers did see distracters in this empty zone, then it was considered to have faded away. To avoid making the task too complex, the observers were not required to press any key upon the perceived reemergence of the surrounding zone.

In Experiment 1, the initial fading times of the target and of its surrounding zone were measured. In Experiment 2, the initial fading time and fading duration of the target were measured, as well as the initial fading time of the surrounding zone. In Experiments 3 and 4, the initial fading time and fading duration of the target were measured.

3. Results and discussion

3.1. Experiment 1: Eccentricity effect

Fig. 5 shows that the initial fading time of the target (Fig. 5A) and the initial fading time of its surrounding zone (Fig. 5B) both decrease with eccentricity, regardless of the kind of distracters used (coherently moving, incoherently moving or completely stationary).

From comparing Fig. 5A and B, it is clear that the target is perceived to fade more easily than its surrounding zone (i.e., the initial fading time was shorter for the target than for its surrounding zone). At small eccentricities, the surrounding zone was rarely perceived to disappear at all. This result replicates Bonneh et al. (2001), who noticed that the surrounding zone (which they called the “protection zone”) seemed protected from the invasion of distracters from the background, even when the targets were not. Fig. 5B, however, shows that, at larger eccentricities, the surrounding zones are perceived to fade as well, just as the targets are. Thus, the existence of a “protection zone” cannot be considered a distinguishing feature of MIB.

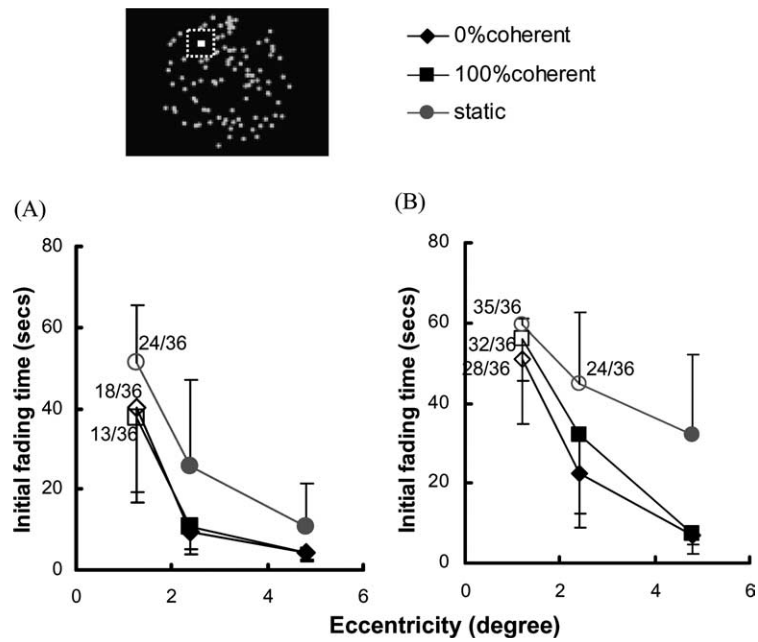

Fig. 5. Results of Experiment 1 (eccentricity effect on MIB). The upper-left pattern shows the display (the white dotted lines indicate the surrounding zone but were not displayed). The average initial fading times of the target are shown on the left (A) and those of the surrounding zone on the right (B). Short fading times indicate strong MIB. The ratios, next to the open symbols, show the proportions of the trials in which the target or its surrounding zone were not perceived to fade. Whenever this was the case, we conservatively assumed the fading time to be equal to the duration of the trial. Error bars show 0.5 standard error.

3.2. Experiment 2: Contrast effects

Fig. 6A and B show that MIB is enhanced (1) when the luminance of the target approaches that of the background (the dotted lines) and (2) when it differs greatly from the luminance of the background [1]. Fig. 6C and D show that PFI is enhanced when the luminance of the target approaches that of the background (near the dotted lines again) but that it is not enhanced when the luminance differs greatly from that of the background.

Fig. 7A shows that MIB is also enhanced when the luminance of the surrounding zone approaches that of the background (near the dotted line) but that it is not enhanced when the luminance differs greatly from that of the background. Thus, the curious contrast effect for targets in MIB is not observed for their surrounding zones. Fig. 7B shows a similar trend when the contrast of the surrounding zone is manipulated by varying the luminance of the target rather than that of the surrounding zone itself. Of course, because the target is quite small, compared to the surrounding zone, the effect of manipulating its luminance is also quite small. In any event, it is clear that there is no indication in either Fig. 7A or B that MIB is enhanced by an increase in the contrast of the surrounding zone. Fig. 7C and D show that, just as with MIB, PFI is also enhanced when the luminance of the surrounding zone approaches that of the background (near the dotted line) and that it is not enhanced when the luminance is far away from that of the background.

In summary, only in the case of Fig. 6A and B, where the luminance of the targets and distracters is quite similar and where grouping could be a factor, is the counter-intuitive contrast effect observed, i.e., an increase in contrast leads to an increase in perceived fading. In all cases, including the ones in Fig. 6A and B, the more intuitive contrast effect is observed in that a reduction in contrast leads to an increase in perceived fading.

[1] Because the effects in Fig. 6A and B seem to be small, we performed a multivariate analysis of variance (MANOVA). Both the luminance of the target and the kind of background used (stationary, coherently moving, or randomly moving) had significant effects on the combination of the two dependent variables (initial fading time and fading duration) [Wilks' $\Lambda = 0.74$, $F(12, 1218) = 15.38$, $p < 0.001$ and Wilks' $\Lambda = 0.41$, $F(4, 1218) = 128.23$, $p < 0.001$, respectively]. Their interaction was not significant. The luminance of the target also had significant effects on the measurements of the initial fading time and fading durations separately [$F(6, 609) = 17.92$, $p < 0.001$ and $F(6, 609) = 16.57$, $p < 0.001$, respectively], and the same was true for the kind of background used [$F(2, 609) = 183.61$, $p < 0.001$ and $F(2, 609) = 243.90$, $p < 0.001$, respectively]. Their interactions were not significant. Planned comparisons showed that the initial fading time was shorter, and the fading duration longer, for low and high luminance values than for intermediate luminance values.

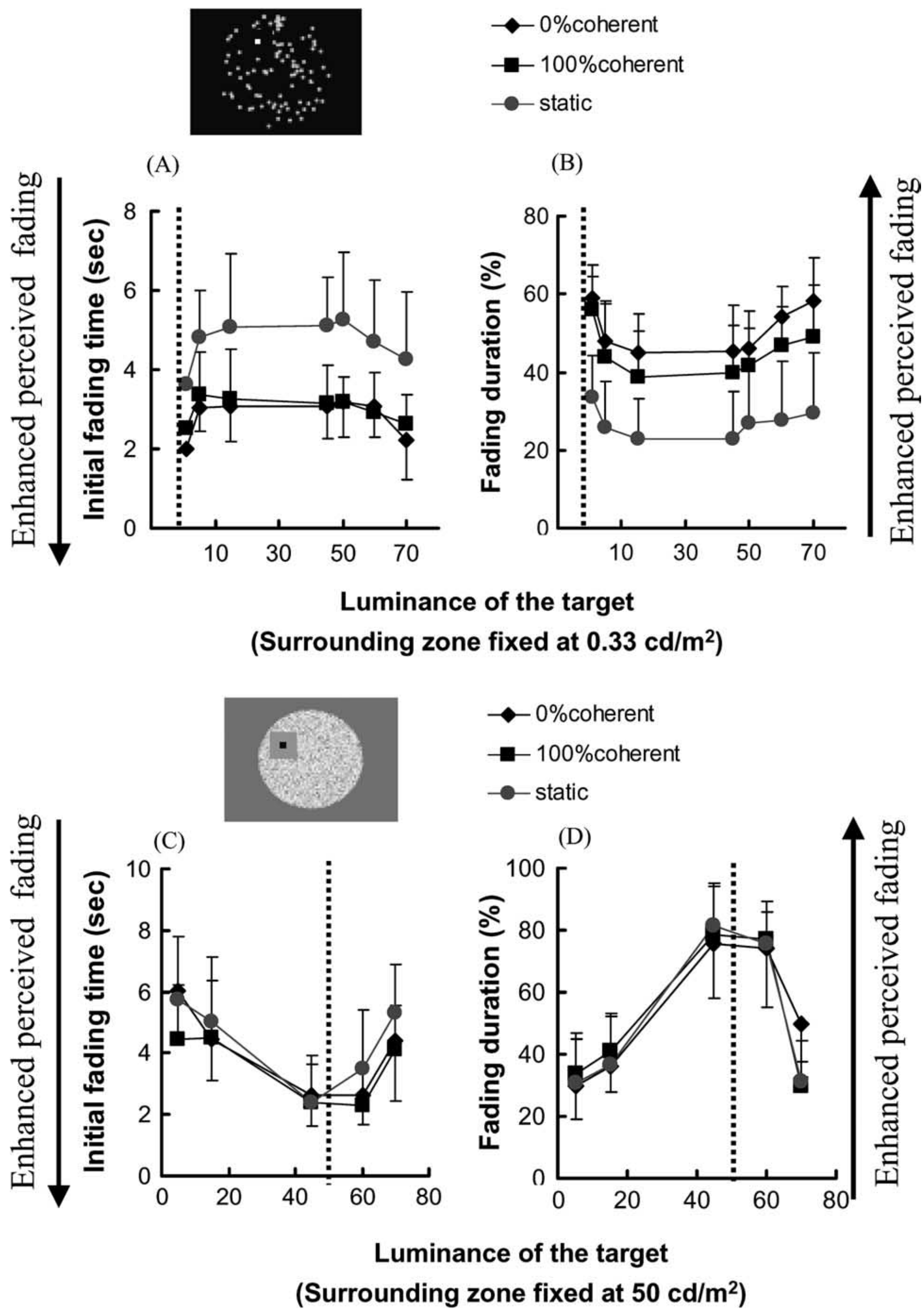

Fig. 6. Results of Experiment 2 (target contrast effects). The upper panel shows the MIB-display used and the average initial fading times (A) and average fading durations (B) as functions of target luminance. The lower panel shows the PFI-display used and the average initial fading times (C) and average fading durations (D) as functions of target luminance. Short fading times and long fading durations indicate strong MIB or PFI. The dotted lines represent the background luminance and minimal target contrast. Error bars show 0.5 standard error.

3.3. Experiments 3 and 4: Perceptual grouping effects

Figs. 8 and 9 both show that MIB is enhanced by poor grouping between targets and distracters and that it is reduced by good grouping between them. Fig. 8 shows that this is true when grouping by similarity of shape is employed, and Fig. 9 shows that it is also true when grouping by continuation is used.

Taken together with the results of Experiment 2, the results of Experiment 3 and 4 suggest that the curious contrast effect observed in Experiment 2 is most likely due to an effect of perceptual grouping. Low luminance targets group better with low luminance distracters than high luminance targets do and, hence, an increase in the luminance (and thus the contrast) of the target should indeed be expected to lead to an increase in MIB.

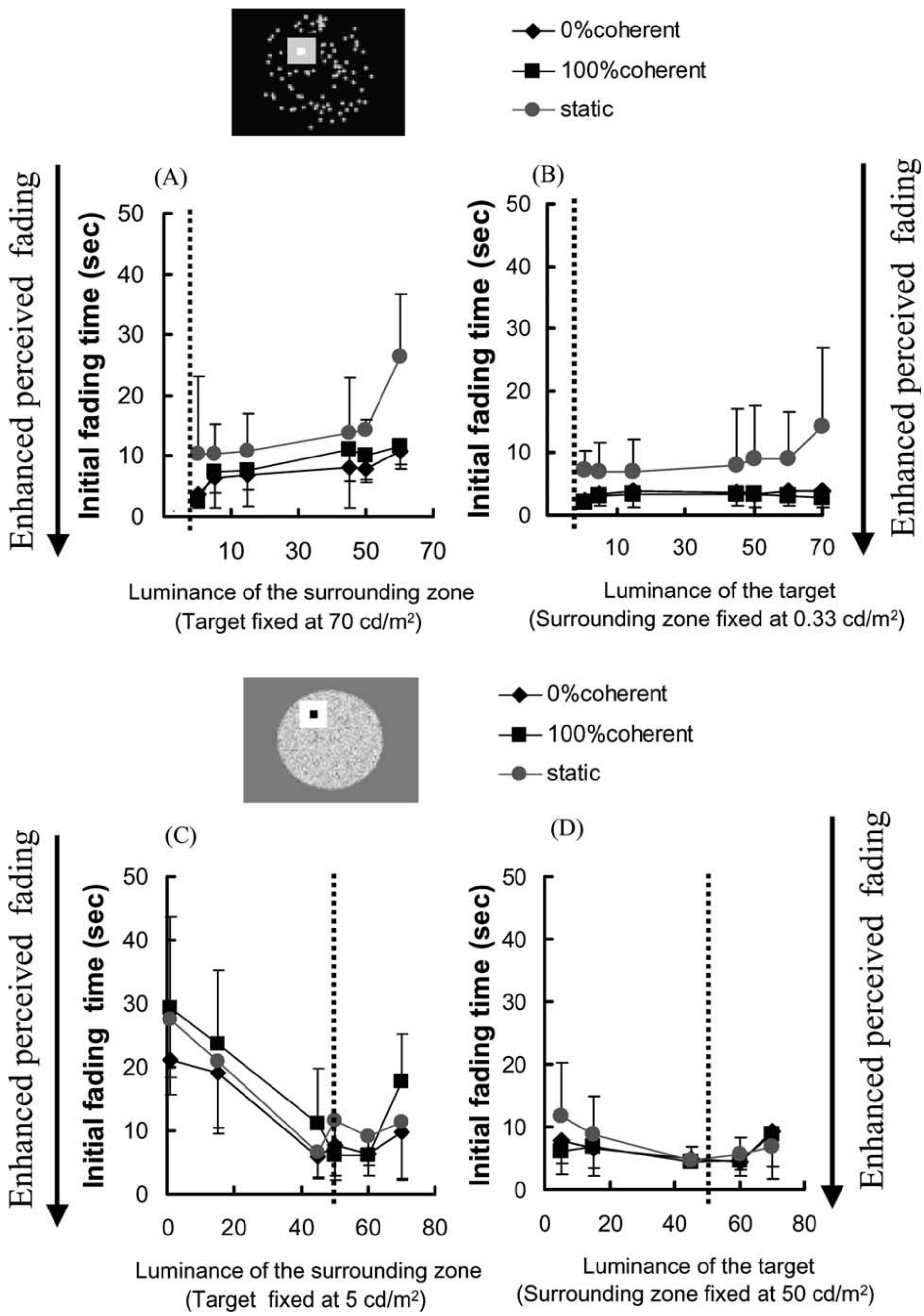

Fig. 7. Results of Experiment 2 (surrounding zone contrast effects). The upper panel shows the MIB-display used and the average initial fading times as a function of the luminance of (A) the surrounding zone and (B) the target. The lower panel shows the PFI-display used and the average initial fading times as a function of the luminance of (C) the surrounding zone and (D) the target. Short fading times indicate strong MIB or PFI. The dotted lines represent the background luminance and minimal contrast of the surrounding zone. Error bars show 0.5 standard error.

Apart from explaining the results of Experiment 2, the results of Experiments 3 and 4 also suggest a possible explanation for the fact that perceived fading is enhanced when distracters are moving rather than remaining stationary (Figs. 5–7 and see also Ramachandran et al., 1993; Spillmann & Kurtenbach, 1992). When the distracters are moving, and the target is stationary, or moving with a different velocity, then the distracters and the target do not group as well with each other as when they are both stationary. The observed increase in perceived fading when the distracters are moving could, therefore, very well be caused by perceptual grouping too. Similarly, our grouping experiments may also explain why perceived fading is enhanced by an introduction of a stereoscopic difference between targets and distracters (Bonneh et al., 2001; Graf, Adams,

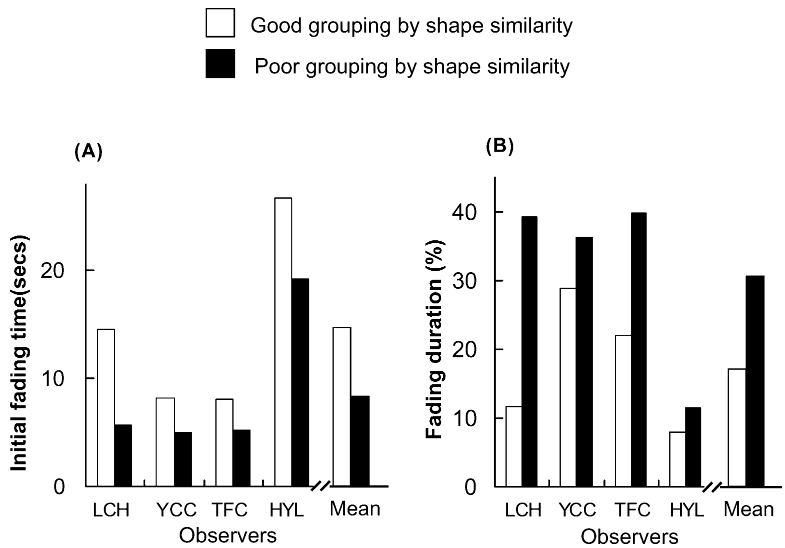

Fig. 8. Results of Experiment 3 (effects of grouping by shape similarity). The average initial fading times (A) and the average fading durations (B) are shown for the good grouping condition (white bars) and the poor grouping condition (black bars).

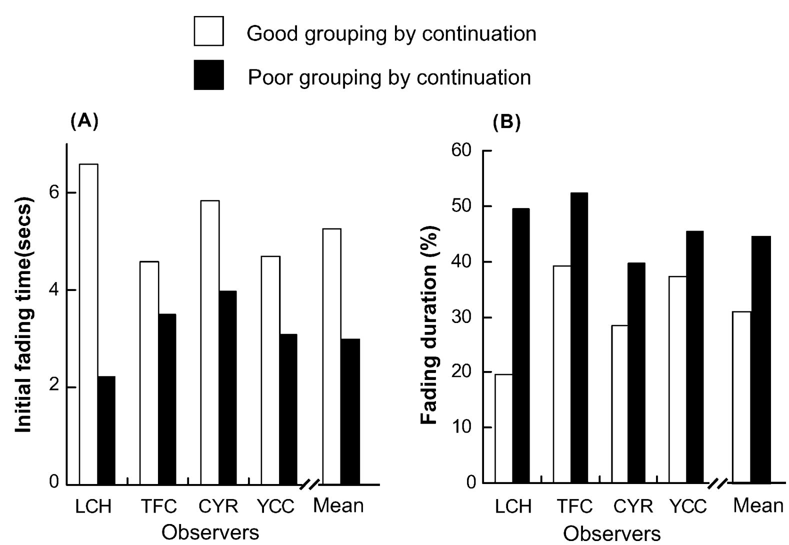

Fig. 9. Results of Experiment 4 (effects of grouping by continuation). The average initial fading times (A) and the average fading durations (B) are shown for the good grouping condition (white bars) and the poor grouping condition (black bars).

& Lages, 2002). In this case too, the grouping between these targets and distracters is weakened.

4. Conclusion

We conclude that MIB and PFI are lawfully related and, by Occam's razor, that they are most likely caused by one common underlying mechanism. When salient stimuli are perceived to fade away, this effect can be enhanced by increasing eccentricity, by reducing contrast, and by minimizing their perceptual grouping with other stimuli.

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