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Monocular depth effects on perceptual fading

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ABSTRACT

After prolonged viewing, a static target among moving non-targets is perceived to repeatedly disappear and reappear. An uncrossed stereoscopic disparity of the target facilitates this *Motion-Induced Blindness* (*MIB*). Here we test whether monocular depth cues can affect MIB too, and whether they can also affect perceptual fading in static displays. Experiment 1 reveals an effect of *interposition*: more MIB when the target appears partially covered by, than when it appears to cover, its surroundings. Experiment 2 shows that the effect is indeed due to interposition and not to the target's contours. Experiment 3 induces depth with the *watercolor illusion* and replicates Experiment 1. Experiments 4 and 5 replicate Experiments 1 and 3 without the use of motion. Since almost any stimulus contains a monocular depth cue, we conclude that perceived depth affects perceptual fading in almost any stimulus, whether dynamic or static.

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1. Introduction

After prolonged viewing, while maintaining fixation, a salient static target among moving non-targets is perceived to repeatedly disappear and reappear (*Motion-Induced Blindness*, or *MIB*; Bonneh, Cooperman, & Sagi, 2001). More MIB is observed if the target has an uncrossed, than if it has a crossed, stereoscopic disparity (Graf, Adams, & Lages, 2002; Hsu, Yeh, & Kramer, 2006; Lages, Adams, & Graf, 2009). Here we hypothesize that this disparity effect generalizes to a depth effect that can also be induced monocularly. We also hypothesize that monocular depth cues do not only affect MIB, but also perceptual fading in static displays. Since almost any stimulus contains a monocular depth cue like *relative location* (Bressan, Garlaschelli, & Barracano, 2003; Vecera, Vogel, & Woodman, 2002), *luminance or texture gradients* (Palmer & Ghose, 2008; Ramachandran, 1988a, 1988b; Todd & Mingolla, 1983), *contrast differences* (O'Shea, Blackburn, & Ono, 1994), and many others, the implication would be that perceived depth should affect perceptual fading in almost any stimulus, whether dynamic or static.

In the current article, we manipulate the perceived depth of an MIB target with the help of two radically different monocular depth cues. The first monocular depth cue is *interposition*. A concave shape (e.g., the black center of the flower-like shape in Fig. 1A) is often perceived as a part of larger region that is positioned behind its surrounding regions. A convex shape (e.g., the black center of the flower-like shape in Fig. 1B), instead, is more likely to be perceived as positioned in front of its surrounding regions (Kanizsa, 1979; Kanizsa & Gerbino, 1976).

The second monocular depth cue is brought about by the *watercolor illusion* (Pinna, Brelstaff, & Spillmann, 2001; Pinna, Werner, & Spillmann, 2003). The illusion is induced by a shape with a double-edged border. If the outside edge has a lighter color than the inside edge (e.g., the triangular shape in Fig. 1C), then the lighter color appears to spread outward, away from this shape. The inside of the shape then appears to be part of a larger background that is visible through a hole, and the dark edge of the shape does not appear to belong to the shape itself, but to the surrounding region. If, instead, the outside edge has a darker color than the inside edge (e.g., the triangular shape in Fig. 1D), then the lighter color appears to spread inward, across the shape. The shape then appears to be an opaque figure with the dark edge belonging to itself rather than to the surrounding region. Thus, in the watercolor illusion, shapes with a double-edged border, colored light outside and dark inside (i.e., shapes that appear to be part of a larger background), tend to be perceived behind their surrounding area, whereas shapes with a double-edged border, colored dark outside and light inside (i.e., shapes that appear to be figures, rather than grounds), tend to be perceived in front of their surrounding area.

Regardless of whether depth is induced with the help of interposition or the watercolor illusion, we predict that more MIB will be observed if the target appears behind its surroundings than

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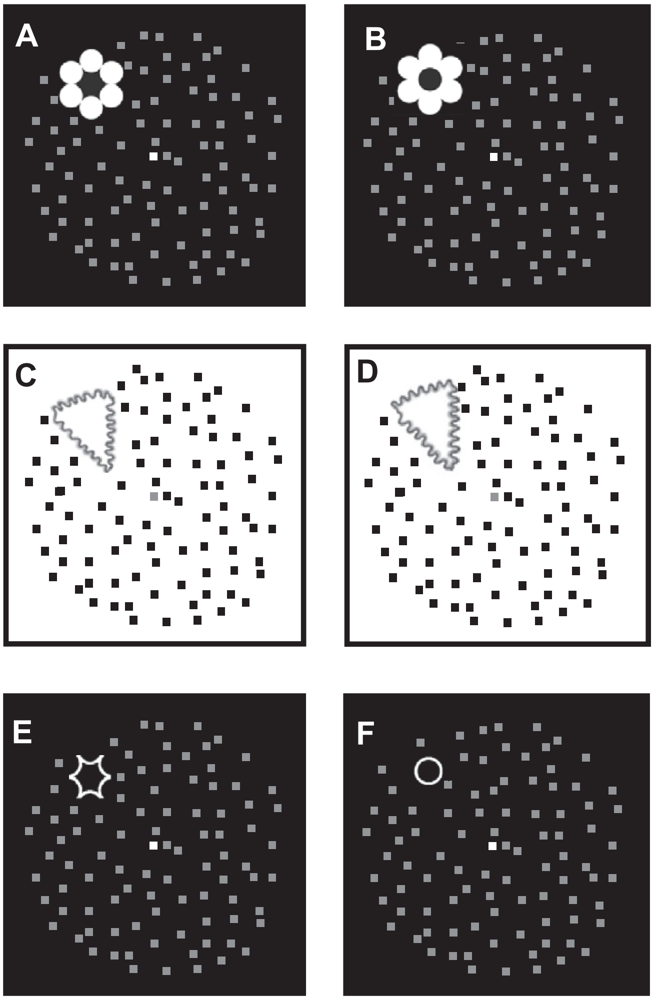

Fig. 1. Illustration of the stimuli (not to scale). The central dot in each panel (red, but here shown in white in Panels A, B, E, and F, and in gray in Panels C and D) represents the fixation marker. The other dots induce MIB of a static target by rotating together in a coherent fashion. In Experiment 1, the target is the concave (Panel A) or convex (Panel B) center of a static flower-like shape. In Experiment 2, the target is the concave (Panel E) or convex (Panel F) outline of the concave (Panel A) or convex (Panel B) target of Experiment 1. In Experiment 3, the target is a triangular shape with a double-edged border of which the outside edge is orange and the inside edge blue (Panel C) or the converse (Panel D). If drawn to scale in the proper colors, the stimulus leads to a watercolor illusion in which the orange color is perceived as either spread away from the target (Panel C) or across it (Panel D). In Experiments 4 and 5, the same stimuli are used as in Experiments 1 (Panels A and B) and 3 (Panels C and D), but without the rotating dots.

when it appears in front of them. Such a result would be consistent with earlier observations that more MIB is observed if a target has an uncrossed disparity, and is perceived behind its surroundings, than if it has a crossed disparity, and is perceived in front of its surroundings (Graf et al., 2002; Hsu et al., 2006). The purpose of the current article is not to investigate whether MIB is a special instance of a more general phenomenon of perceptual fading. Yet, the question does arise whether monocular depth cues could not only affect MIB, but also perceptual fading in static displays. We therefore conclude our investigation with two experiments that are identical to two of our MIB experiments, except that they do not contain any motion.

2. Experiment 1: interposition effects on MIB

In the current experiment, we manipulate the perceived depth of an MIB target with the help of interposition. We predict that more MIB will be observed when the target is concave (the center of the flower-like shape in Fig. 1A) and appears to be positioned behind its static surrounding areas than when it is convex (the center of the flower-like shape in Fig. 1B) and appears to be positioned in front of its surrounding areas. The assumption that the concave targets are more likely to be perceived behind their surrounding regions than the convex ones is based on Kanizsa (1979) and Kanizsa and Gerbino (1976). In a control experiment, however, we test the validity of this assumption for the specific stimuli used here by using the participants' subjective reports of perceived depth.

Note that, whereas any region may be subject to perceptual fading, large ones are less susceptible to it than small ones (De Weerd, Desimone, & Ungerleider, 1998; Hsu et al., 2006). In addition, small regions are less likely to be perceived to fade away when grouped into large arrays with other small regions than when observed in isolation (Bonneh et al., 2001; Hsu, Yeh, & Kramer, 2004). As a result, in our specific experiments, only our relatively small targets are perceived to fade away, whereas their surrounding regions, forming a relatively large group, remain visible.

2.1. Method

2.1.1. Apparatus

The stimuli were constructed with, and controlled by, Presentation v0.80 software (Neural Behavior Systems Corporation), using an IBM compatible personal computer with a 22 in. calibrated ViewSonic color monitor.

2.1.2. Participants

Thirty-four undergraduates participated in the experiment (main experiment: $N = 19$; control experiment: $N = 15$). As in all our current experiments, unless otherwise indicated, the participants were undergraduates of the China Medical University, naïve, had normal or corrected to normal vision, and participated for a small payment.

2.1.3. Stimuli

The stimuli (Fig. 1A and B) contained a small, central, red square (the fixation marker; 21.28 cd/m^2, CIE (0.602, 0.322), area = 0.27° $\times$ 0.27°), and a blue, peripheral target (9.35 cd/m^2, CIE (0.151, 0.070)) in the upper-left of the screen, 13.5° away from the fixation marker, surrounded by gray stationary regions containing six disks (50 cd/m^2, radius = 1.53°). Consistent with typical MIB displays, our stimuli also contained 100 blue random dots (little squares, 0.27° $\times$ 0.27°, 9.35 cd/m^2, CIE (0.151, 0.070), density = 1%) sparsely distributed over a circular area (radius = 12.15°) that rotated clockwise with a speed of 0.28 revolutions per second, on a black (0.01 cd/m^2) field. The ambient illumination was minimal. Viewing distance was 65 cm.

The target could be either concave (Fig. 1A) or convex (Fig. 1B). We hypothesize that the concave targets should lead to more perceptual fading than the convex ones. The smaller the target is, the longer its perceptual fading and the shorter the onset of the fading (De Weerd et al., 1998; Hsu et al., 2006). To ensure that small measurement error of the target size would not confound our results, we conservatively stacked the deck against our hypothesis, and chose slightly larger concave targets (2.99 deg^2) than convex ones (2.71 deg^2).

2.1.4. Design and procedure

The experiment had a completely pseudo-randomized within-subjects design. After fixating the small red square, the observers initiated a trial by pressing the enter key with either the left or right hand. Next, the left-arrow key was to be pressed with the right hand as soon as the target appeared to have faded away, and the right-arrow key, also with the right hand, as soon as the target appeared to have reemerged. Each observer performed 12 one-minute trials: two different target shapes (Fig. 1A and B) × 6 replications. To prevent fatigue, self-paced short breaks were allowed in between trials.

A control experiment was conducted to assess whether, as assumed, the concave target was indeed more likely than the convex one to be perceived behind the stationary surrounding regions. After fixating the red central square, participants pressed the left-arrow key if they perceived the target behind the surrounding regions, and the right-arrow key if they perceived the target in front of these regions (arrow-key assignment was counterbalanced between participants). After the response, the stimulus disappeared, and the next trial began. The control experiment contained 40 trials: two different target shapes (Fig. 1A and B) × 20 replications, and was preceded by five practice trials.

2.2. Results and discussion

The computer program that ran the experiment also registered the percentage of each trial's duration in which the target had not been perceived (the *fading duration*; Fig. 2A) and, as a second indication of perceptual fading, also the time until the target's first perceived disappearance (the *initial fading time*). The fading duration and initial fading time results show very similar patterns and thus we show only the fading duration results in the figure. Two t-tests corroborated our hypothesis (all our t-tests were two-tailed paired-sample t-tests). They revealed that the concave targets produced longer fading durations ($t(18) = 3.31$, $p < 0.01$, bias-corrected Cohen's $d = 0.45$), and shorter initial fading times ($t(18) = 2.64$, $p < 0.05$, bias-corrected Cohen's $d = 0.54$), than the convex ones. Fading durations were 32.9% for the concave, and 25.2% for the convex, targets. Initial fading times were 15.6 s for the concave, and 21.5 s, for the convex targets. The control experiment confirmed that the concave targets were more often perceived behind their surrounding regions than the convex ones (Fig. 2A, inset; $t(14) = 8.37$, $p < 0.01$, bias-corrected Cohen's $d = 3.62$). Hence, consistent with our hypothesis, the target was perceived to fade away both longer, and earlier, when it was perceived behind its surrounding regions than when it was perceived in front of them.

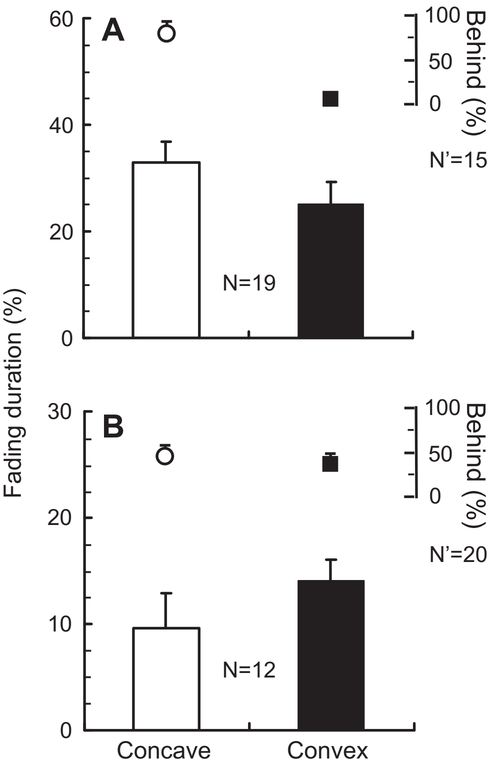

Fig. 2. Results of Experiments 1 and 2 (Panels A and B, respectively) obtained with a concave (open bars and symbols) or convex (closed bars and symbols) target. Panels A and B show the target's fading duration as a percentage of the trial duration (1 min). The inset at the top of each panel shows the percentage of the trials on which control experiment participants perceived the target as behind its surroundings. Error bars represent one standard error of the mean. N and N' represent, respectively, the number of subjects in the main and control experiments.

3. Experiment 2: target shape effects on MIB

The results of Experiment 1 were consistent with our hypothesis that monocularly induced depth affects MIB. The two different targets that we used, however, not only induced different depth percepts, but also had different shapes. The question is whether the depth percepts, or the shapes themselves, produced the observed effects. To answer this question, the targets in the current experiment have the same shape as they had in Experiment 1, but are not surrounded by the static areas that were present in Experiment 1 (compare Fig. 1E and F with Fig. 1A and B). Interposition, in this case, does not play any role, and the concave and convex targets do not induce different percepts of depth. If target shape was responsible for the effects in Experiment 1, then the current experiment should produce similar results. If not, then we argue that the current experiment should produce the very opposite results. Hsu et al. (2006), namely, found more MIB for targets with a short boundary than for targets with a long boundary (most likely due to the fact that short boundaries are more susceptible to adaptation than long ones, see Hsu et al., 2006; for a similar effect in the phenomenon of perceptual filling-in, see De Weerd et al., 1998). In the current experiment, the concave target has a longer boundary than the convex one. It therefore follows that in the current experiment, unlike in Experiment 1, the convex target should produce more MIB than the concave one.

3.1. Method

3.1.1. Participants

Thirty-two undergraduates participated in the experiment (main experiment: $N = 12$; control experiment: $N = 20$).

3.1.2. Apparatus, design, stimuli, and procedure

The same apparatus, design, stimuli, and procedure were used as in Experiment 1, except that the targets were similar to those shown in Fig. 1E and F and consisted in the contours of the targets used in Experiment 1 (width = 0.27°, 10 cd/m^2).

3.2. Results and discussion

Corroborating our hypothesis, convex targets produced longer fading durations (Fig. 2B; $t(11) = 2.56$, $p < 0.05$, bias-corrected Cohen's $d = 0.60$), and shorter initial fading times ($t(11) = 2.92$, $p < 0.01$, bias-corrected Cohen's $d = 0.88$), than the concave ones. Fading durations were 9.5% for the concave, and 14.1% for the convex, targets. Initial fading times were 22.8 s for the concave, and 14.2 s, for the convex targets. The result is opposite to that found in Experiment 1. The control experiment showed that there was no difference in the perceived depth of the convex and concave targets (Fig. 2B, inset; $t(19) = 1.12$, $p = 0.28$). Thus, in this experiment in which interposition played no role, consistent with earlier findings by Hsu et al. (2006), it was the targets' contour length that was critical.

4. Experiment 3: watercolor effects on MIB

In Experiment 1, we induced depth with the monocular depth cue of interposition. In the current experiment, we induce depth with the monocular depth cue of the *watercolor illusion* (Pinna, Brelstaff, et al., 2001; Pinna, Werner, et al., 2003). Either the outside edge of the target is given a lighter color than the inside edge (Fig. 1C), which leads to the tendency to perceive the target behind its surrounding region, or the reverse (Fig. 1D), which leads to the tendency to perceive the target in front of its surrounding region. As in Experiment 1, we hypothesize that the targets perceived behind their surrounding region should lead to more MIB than the targets perceived in front of it. We, once again, perform a control experiment to verify whether the two types of targets do indeed produce two different depth percepts.

4.1. Method

4.1.1. Participants

Twenty-five undergraduates participated in the experiment (main experiment, with all participants from National Taiwan University: $N = 8$; control experiment: $N = 17$).

4.1.2. Apparatus, design, stimuli, and procedure

The target was approximately triangular (base = 2.36°, height = 3.23°) and its main axis was oriented at a counterclockwise angle of 20.6°. The triangle's border either had an orange outside edge (40.5 cd/m^2, CIE (0.496, 0.433)) and a blue inside edge (2.68 cd/m^2, CIE (0.159, 0.084)) or the converse. The eccentricity of the target (measured from fixation to the target's center of gravity) was either 2.80°, 4.37°, or 5.95°, and the target was presented on a white field (100 cd/m^2), and contained 100 sparsely distributed (1% density) random, black dots (little squares, $0.27° \times 0.27°$, 0.01 cd/m^2). The black dots were contained in an area with a radius of 12.15°, and rotated together (clockwise) with a speed of 0.28 revolutions per second. The dots were never presented inside the triangular target. Each observer performed 36 one-minute trials: two different edge colorations (Fig. 1C and D) × 3 eccentricities × 6 replications. The design and procedure were similar to the one used in Experiments 1 and 2. The control experiment consisted of 120 trials: 2 configurations (Fig. 1C and D) × 3 eccentricities × 20 replications.

4.2. Results and discussion

Defining a *light–dark* target-border as light outside and dark inside (as in Fig. 1C) and a *dark–light* target-border as dark outside and light inside (as in Fig. 1D), two separate repeated-measures ANOVAs revealed the following. The fading durations were longer (Fig. 3A; $F(1,7) = 8.94$, $p < 0.05$, $\eta_p^2 = 0.56$), and the initial fading times shorter ($F(1,7) = 8.72$, $p < 0.05$, $\eta_p^2 = 0.56$), when the target's border was light–dark (target perceived behind its surrounding region) than when it was dark–light (target perceived in front of its surrounding region). Fading durations were 19.0% for the target with the light–dark border and 14.1% for the target with the dark–light border. Initial fading times were 16.3 s for the target with the light–dark border and 19.9 s for the target with the dark–light border. Fading durations increased ($F(2,14) = 5.77$, $p < 0.05$, $\eta_p^2 = 0.45$), and initial fading times decreased ($F(2,14) = 3.88$, $p < 0.05$, $\eta_p^2 = 0.36$), with target eccentricity. There were no interactions, neither for the fading durations, nor for the initial fading times (both $F(2,14) < 1$). Tukey post hoc comparisons showed that the targets led to longer fading durations, and shorter initial fading times, when they were 5.95° away from fixation than when they were 2.80° away from fixation (both $ps < 0.05$).

For the control experiment, a two-way repeated-measures ANOVA revealed that the targets were more often seen behind the surrounding regions when the target's border was light–dark than when it was dark–light (Fig. 3A, inset; $F(1,16) = 498.58$, $p < 0.01$, $\eta_p^2 = 0.97$). The effect of target eccentricity was not significant, and did not interact with target-border type (both $F(2,32) < 1.5$).

Thus, although we kept target shape constant in the current experiment, we once again obtained more MIB when the target

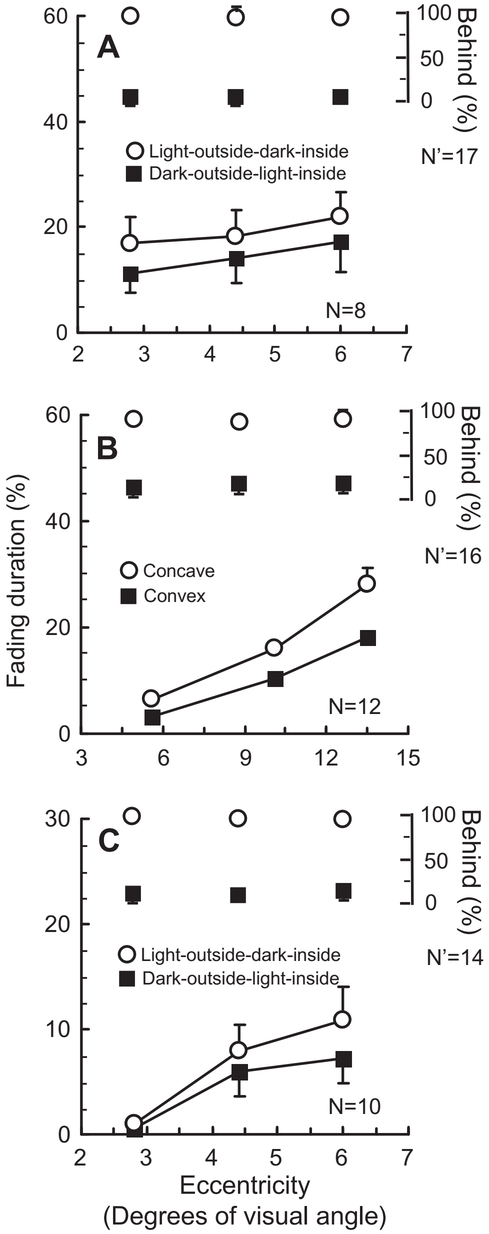

Fig. 3. Results of Experiments 3–5 (Panels A–C, respectively). In Experiments 3 and 5, the results were obtained with a target that either had a light outside and dark inside edge (open symbols) or a dark outside and light inside edge (closed symbols). In Experiment 4, the results were obtained with a concave (open symbols) or convex (closed symbols) target. Panels A–C show the target's fading duration as a percentage of the trial duration for three different target eccentricities (the eccentricities are measured from fixation to the target's center of gravity). The inset at the top of each panel shows the percentage of the trials on which control experiment participants perceived the target as behind its surroundings. Error bars represent one standard error of the mean (wherever they are not shown, they are smaller than the symbols). *N* and *N'* represent, respectively, the number of subjects in the main and control experiments.

was perceived behind its surroundings than when it was perceived in front of them. The control experiment also once again corroborated our assumptions about the perceived depth of the targets in the main experiment. That we obtained more MIB with increasing eccentricity is consistent with earlier findings by Hsu, Yeh, and Kramer (2004). Given that perceived depth was induced in a very different way in the current experiment than in Experiment 1, the effect of perceived depth on MIB appears to be general and not specific to the monocular depth cue of interposition used in Experiment 1.

5. Experiment 4: interposition effects on perceptual fading in static displays

Experiments 1–3 demonstrate that monocular depth cues affect MIB in the same way as binocular ones do. The question is whether monocular depth cues only affect MIB, or could also affect perceptual fading in static displays. Here, to answer this question, we attempt a replication of Experiment 1 without the use of moving dots or any other kind of motion or flicker (for perceptual fading in static displays, see also Gorea & Caetta, 2009; for perceptual fading induced by flicker, see Kawabe & Miura, 2007; New & Scholl, 2008).

5.1. Method

5.1.1. Participants

Twenty-eight undergraduates participated in the experiment (main experiment: $N = 12$; control experiment: $N = 16$).

5.1.2. Apparatus, design, procedure, and stimuli

The same apparatus, design, and procedure were used as in Experiment 1. The stimuli were also similar, but did not contain moving dots. As in Experiment 1, we used the target eccentricity of 13.5° (measured from fixation to the target's center of gravity), but in addition, we also used the eccentricities of 10.1° and 5.6°. Each observer performed 36 one-minute trials: 2 different target shapes $\times$ 3 eccentricities $\times$ 6 replications.

5.2. Results and discussion

Two separate repeated-measures ANOVAs revealed that the concave targets produced longer fading durations (Fig. 3B; $F(1,11)=20.62$, $p < 0.01$, $\eta_p^2 = 0.65$), and shorter initial fading times ($F(1,11)=7.34$, $p < 0.05$, $\eta_p^2 = 0.40$), than the convex targets. Fading durations were 16.7% for the concave, and 10.6% for the convex, targets. Initial fading times were 27.3 s for the concave, and 34.4 s, for the convex targets. As in MIB (Hsu et al., 2004), fading durations increased ($F(2,22) = 78.41$, $p < 0.01$, $\eta_p^2 = 0.88$), and initial fading times decreased ($F(2,22) = 43.54$, $p < 0.01$, $\eta_p^2 = 0.80$), with target eccentricity. Interactions between target shape and eccentricity reached significance in neither the fading durations ($F(2,22) = 2.92$, $p = 0.08$), nor the initial fading times ($F(2,22) < 1$).

As predicted, and as in Experiment 1, a two-way repeated-measures ANOVA for the control experiment revealed that the concave targets were more often seen behind the surrounding regions than the convex targets were (Fig. 3B, inset; $F(1,15) = 388.95$, $p < 0.01$, $\eta_p^2 = 0.96$). There was neither an effect of target eccentricity, nor an interaction effect of target eccentricity with target shape (both $F(2,30) < 1$). Together, the results of the main and control experiments thus demonstrate that monocular depth cues not only affect MIB, but also perceptual fading in static displays.

6. Experiment 5: watercolor effects on perceptual fading in static displays

In Experiment 4, we replicated Experiment 1 without any use of motion or flicker. Here we attempt to replicate Experiment 3 in this way.

6.1. Method

6.1.1. Participants

Twenty-four undergraduates participated in the experiment (main experiment: $N = 10$; control experiment: $N = 14$).

6.1.2. Apparatus, design, procedure, and stimuli

The same apparatus, design, and procedure were used as in Experiment 3. The stimuli were also similar, but did not contain moving dots.

6.2. Results and discussion

The two separate repeated-measures ANOVAs revealed that the targets with a light–dark border (perceived behind their surrounding region) produced longer fading durations (Fig. 3C; $F(1,9) = 10.84$, $p < 0.01$, $\eta_p^2 = 0.55$), and shorter initial fading times, ($F(1,9) = 79.41$, $p < 0.01$, $\eta_p^2 = 0.90$), than the targets with a dark–light border (perceived in front of their surrounding region). Fading durations were 6.6% for the target with the light–dark border and 4.6% for the target with the dark–light border. Initial fading times were 30.8 s for the target with the light–dark border and 40.0 s for the target with the dark–light border. As in MIB (Hsu et al., 2004), fading durations increased ($F(2,18) = 7.81$, $p < 0.01$, $\eta_p^2 = 0.46$), and initial fading times decreased ($F(2,18) = 26.51$, $p < 0.01$, $\eta_p^2 = 0.75$), with target eccentricity. Although target-border type interacted with eccentricity in the fading duration data, the interaction was likely due to a floor effect at the smallest eccentricity (Fig. 3C), and its effect size was relatively small ($F(2,18) = 3.71$, $p < 0.05$, $\eta_p^2 = 0.28$). Target shape did not interact with eccentricity in the initial fading time data ($F(2,18) < 1$), which did not suffer from a floor effect.

For the control experiment, we performed a two-way repeated-measures ANOVA with the factors of target-border type and target eccentricity. As predicted, and as in Experiment 3, the targets with a light–dark border were more often seen behind their surrounding region than the targets with a dark–light border (Fig. 3C, inset; $F(1,13) = 1074.21$, $p < 0.01$, $\eta_p^2 = 0.98$). There was neither an effect of target eccentricity, nor an interaction effect of target-border type with target eccentricity (both $F(2,26) < 1$). The results of the main and control experiments together thus once again demonstrate that monocular depth cues not only affect MIB, but also perceptual fading in static displays.

7. General discussion

In Experiment 1, we found that the monocular depth cue of interposition affected MIB; more MIB was observed for the concave target that was perceived behind its surroundings than for the convex target that was perceived in front of them. Experiment 2 was similar to Experiment 1, but the depth cue of interposition was absent, and opposite results were obtained; more MIB was observed for the convex target, which has a relatively short boundary, than for the concave target, which has a relatively long boundary (consistent with earlier findings by Hsu et al., 2006). In Experiment 3, we induced depth with the help of the watercolor illusion. Despite that depth was induced in a very different way in Experiment 3 than in Experiment 1, their results were similar. In Experiments

4 and 5, although effects were smaller, we replicated Experiments 1 and 3 without the use of any motion. All experiments were accompanied by control experiments that confirmed that our assumptions about the perceived depth of the targets were justified. We conclude that perceived depth, whether induced binocularly (Hsu et al., 2006) or monocularly (current study), affects both MIB and perceptual fading in static displays.

The number of hitherto identified monocular depth cues is quite large, and almost any stimulus contains at least one of them. In addition to the monocular depth cues we mentioned in the Introduction, there are also the cues of *relative motion* (whereby faster elements tend to be perceived in front of slower ones; Bruce & Green, 1985) and *relative size* (whereby larger elements tend to be perceived in front of smaller ones; DeLucia, 1991; Tommasi, Bressan, & Vallortigara, 1995). These two depth cues happen to be quite prominent in typical MIB displays, along with the cue of *interposition* (discussed in the Introduction). Interposition plays a role, because the targets seem to occlude passing non-targets, and as a result, appear positioned in front of the non-targets. Relative motion, instead, places the targets behind the non-targets, because the latter are moving and the former are not. Relative size too places the targets behind the passing non-targets, because the non-targets—due to their coherent motion—are perceived to group together into one large transparent surface (Nakayama, He, & Shimojo, 1995), and this surface is much bigger than that of the targets. With the conflict between the depth cue of interposition on the one hand, and the depth cues of relative motion and relative size on the other hand, the perceived depth of the targets in a typical MIB display may not be stable. If perceived depth in MIB displays were indeed unstable, then—given that the current article has shown that MIB depends on perceived depth—MIB should be expected to be unstable too. Indeed, instability is the very hallmark of MIB in which targets repeatedly disappear and reappear without end.

Graf et al. (2002), Hsu et al. (2006), and Lages et al. (2009) have all shown that more MIB is observed if the target has an uncrossed, than if it has a crossed disparity. In the current study, we have shown that more MIB is observed, and also more perceptual fading in general, if monocular depth cues place the target behind its surroundings rather than in front of them. The reason for these perceived depth effects on perceptual fading remains an open question. Graf et al. (2002) and Lages et al. (2009) argue that the completion of a surface across a target causes the perceived disappearance of that target. In typical MIB displays, however, the surface that seems to complete across the target consists of (coherently moving) dots. As Hsu et al. (2006) point out, it is not clear why such a collection of dots should be perceived as an opaque surface rather than as a transparent one. Grossberg and colleagues (e.g., Kelly & Grossberg, 2000; Grossberg & Yazdanbakhsh, 2005) proposed a model in which nearby boundaries inhibit those further away. Perhaps this could explain why targets disappear more easily when they are perceived behind distracters than when they are perceived in front of them. In the model, though, the inhibition only occurs for overlapping boundaries. The model would therefore have to be adjusted to explain perceived depth effects on the perceptual fading that we have observed here and in Hsu et al. (2006) with stimuli that do not contain overlapping boundaries. Regardless of any definitive explanation for why perceived depth affects perceptual fading, however, the effect itself has now been independently replicated several times in both the present study and earlier ones (Graf et al., 2002; Hsu et al., 2006; Lages et al., 2009).

MIB requires prolonged fixation, and such fixation can have dramatic effects on perceived depth. Prolonged fixation of a Necker cube, for example, causes the automatic perceptual reversal of its front and back sides and the emergence of a qualitatively different depth percept of the very same stimulus. A phenomenon that is, of course, particularly dependent on prolonged fixation is adaptation. Hsu et al. (2006) demonstrate that MIB increases with prior adaptation to the target's boundary and decreases with the length of this boundary (which increases its adaptation time). Moreover, Lages et al. (2009) show that a motion aftereffect, induced by prior adaptation, can cause MIB in physically static displays. They report that it was not the illusory motion per se, but the relative illusory motion between the targets and the non-targets that was critical. Relative motion is a strong monocular depth cue. We therefore suggest that the adaptation of depth percepts, like those caused by relative motion, may be particularly worthy of future study. It may be an interplay between various different kinds of adaptation that plays a critical role in MIB and perceptual fading in general.

In the so-called Troxler effect, a peripheral target is perceived to fade away after prolonged fixation of a static display (Troxler, 1804; see also Gerrits, De Haan, & Vendrik, 1966; González, Weinstock, & Steinbach, 2007). In Experiments 4 and 5, a target is also perceived to fade away after prolonged fixation of a static display. The perceptual fading in Experiments 4 and 5, however, depends on perceived depth. Future study will have to determine whether perceived fading must necessarily depend on perceived depth or whether there could be fading phenomena that depend on perceived depth and other ones that do not.

Although we found more perceptual fading in dynamic than in static stimuli, in both we found similar monocular depth cue effects. This raises the question whether the perceptual fading observed in Experiments 4 and 5 and in the Troxler effect could be related to MIB. There are indeed some striking similarities between the latter two phenomena. In both the Troxler effect and MIB, perceptual fading decreases with target size, and increases with target eccentricity and adaptation duration (e.g., Gerrits et al., 1966; González et al., 2007; Hsu et al., 2004; Hsu et al., 2006). Although less perceptual fading is observed in static displays than in MIB displays, the target's adaptation time-course in the two conditions is quite similar (Gorea & Caetta, 2009). The Troxler effect and MIB are also both facilitated by low contrast (e.g., Gerrits et al., 1966; González et al., 2007; Hsu et al., 2004; Hsu et al., 2006). Unlike the Troxler effect, MIB is also facilitated by high contrast (Bonneh et al., 2001; Hsu et al., 2004). That is, MIB is a U-shaped function of contrast. Hsu et al. (2004), however, argued that an increase in target contrast in MIB reduces the perceptual grouping between the targets and the low-contrast non-targets. It could thus be the poor perceptual grouping, rather than the high contrast, that facilitates perceptual fading in MIB. Indeed, manipulating perceptual grouping in two different experiments, Hsu et al. (2004) found that MIB is inversely related to the strength of perceptual grouping between targets and non-targets. More research is necessary, however, to determine whether perceptual grouping only affects MIB or also the Troxler effect. In general, more research is also necessary to compare MIB and the Troxler effect directly, under comparable conditions, in a way similar to the direct comparisons between MIB and the phenomenon of perceptual filling-in in Hsu et al. (2004, 2006).

For now, we conclude that the effect of disparity on MIB found by Graf et al. (2002), Hsu et al. (2006), and Lages et al. (2009) is an instance of a general depth effect that can also be induced monocularly and does not only affect MIB, but also perceptual fading in static displays. Given that there is hardly any stimulus that does not contain at least one monocular depth cue, we also conclude that perceived depth affects perceptual fading in almost any stimulus, whether dynamic or static.

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