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Increment of the extinction illusion by long stimulation

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Abstract. We quantitatively examined the effect of stimulus duration on the extinction illusion. A white disc was presented or not presented at an intersection of a grey grid (intersection configuration) or on a homogeneous background (background configuration). The extinction illusion was quantified as the subtraction of no-disc responses in the background configuration (ie baseline) from no-disc responses in the intersection configuration, when the disc was presented. Experiment 1 showed a temporal effect: the extinction illusion increased as stimulus duration increased; this temporal effect was observed when the disc was presented at 9 deg from the fixation point and when the stimulus duration was 1000 – 6000 ms. Experiment 2 showed a visual field anisotropy: the extinction illusion occurred more frequently in the upper visual field than in the lower visual field, when the stimulus duration was 200 ms; the anisotropy was not observed when the stimulus duration was 6000 ms. Experiment 3 showed an alley-length effect: when the grid alley was long, the extinction illusion occurred more frequently in the 6000 ms condition than in the 200 ms condition; the temporal effect was not observed when the grid alley was short. These results suggest that the temporal effect of the extinction illusion might be due to perceptual filling-in of luminance information of the grid alley.

1 Introduction

When white discs surrounded by a thin black circumference are presented at the intersections of a grey grid on a black background as shown in figure 1a, observers do not perceive all the discs (Ninio and Stevens 2000). This phenomenon also occurs when black discs surrounded by a thin white circumference are presented at the intersections of a grey grid on a white background. We hereafter call this phenomenon the 'extinction illusion' in accordance with Ninio and Stevens's terminology.

The extinction illusion has been investigated with regard to the contrast sensitivity of disc stimulus (Howe and Livingstone 2007; Levine and McAnany 2008; McAnany and Levine 2004, 2005). McAnany and Levine (2004) showed that the contrast sensitivity of a lighter disc (ie disc lighter than a grey grid or background) presented at an intersection of the grey grid on the black background was lower than that of the lighter disc presented on a homogeneous grey background. Moreover, when a disc was presented at an intersection of the grey grid on the black background, the contrast sensitivity of the lighter disc was lower than that of a darker disc (ie disc darker than the grey grid). McAnany and Levine (2004) referred to this as the 'blanking phenomenon'.

(a)
(b)

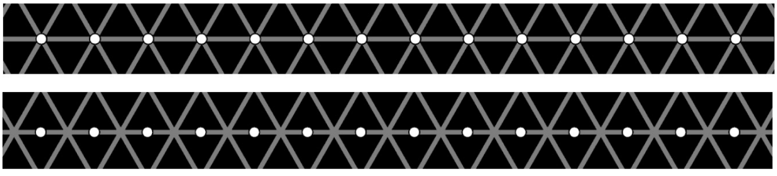

Figure 1. Stimuli in our preliminary observations. These stimuli were a part of figure 4 of Ninio and Stevens (2000). (a) At the instant we fixated on the white disc at the farthest left side of the stimuli, four discs on the left side were perceived. When we fixated on it longer, only three discs on the left side were perceived. (b) At the instant we fixated on the white disc at the farthest left side of the stimuli, more discs were perceived than could be counted.

A spatial property of the extinction illusion reported by McAnany and Levine (2004) was a visual field anisotropy: the contrast sensitivity of the lighter disc presented at an intersection of the grey grid on the black background was lower in the upper visual field than in the lower visual field. On the other hand, there was only slight anisotropy in the contrast sensitivity of the darker disc presented at an intersection of the grey grid on the black background.

A reported temporal property of the extinction illusion was that the occurrence of the extinction illusion does not depend on stimulus duration. McAnany and Levine (2004, 2005) reported that the extinction illusion occurred immediately when stimuli were presented and persisted for as long as fixation was approximately maintained.

On the other hand, our preliminary observations suggested that the probability that the extinction illusion occurs (hereafter 'extinction probability') depends on stimulus duration. At the instant we observed the stimuli as shown in figure 1a, many discs located at the far side of the gaze position were not perceived. Moreover, when we observed the stimuli for a longer time, a few discs located at the far side of gaze position that were initially perceived were no longer perceived. Ninio and Stevens (2000) reported a similar phenomenon: "On shifting the eyes then holding fixation, all but a very few disks, generally in the vicinity of the point of gaze, disappear; elsewhere, the alleys appear uniform in brightness, as though they had been completed by a filling-in process. Different clusters of disks pop into visibility as the eyes fixate across the pattern, and within seconds only a few remain other than the given disk under fixation" (page 1214). Their reports and our preliminary observations suggest that extinction probability depends on stimulus duration, and that the occurrence of the extinction illusion might depend on the retinal eccentricity of the disc. In the present study, the increment in the extinction probability dependent on stimulus duration is termed the 'temporal effect' of the extinction illusion.

The temporal effect of the extinction illusion might lend support to the dual-stage theory of the extinction illusion proposed by McAnany and Levine (2005). They examined whether the extinction illusion was due to a pre-fusion mechanism and/or a post-fusion mechanism with dichoptic viewing. Their results indicated that both pre- and post-fusion processing contributed to the extinction illusion. In their dual-stage theory of the extinction illusion, they proposed that the first stage (pre-fusion stage) was based on lateral antagonism. On the other hand, they did not propose a specific cortical mechanism for the second stage (post-fusion stage). The temporal effect might be based on a cortical mechanism corresponding to the second stage, since the temporal effect would be due to additional processing following the first processing. An examination of the temporal effect would be worthwhile in exploring a possible cortical mechanism.

In the present study, we quantitatively examined the effect of stimulus duration on the extinction illusion. We measured the no-disc response when the disc was presented. In experiment 1 we examined the effects of stimulus duration and the retinal eccentricity of the disc on the extinction illusion. In experiment 2 we examined the effect of the visual field on the temporal effect of the extinction illusion, to examine whether the temporal effect was due to attention or perceptual filling-in (ie perceptual fading or the Troxler effect). In experiment 3 we examined the effect of the length of the grid alley on the temporal effect of the extinction illusion, to explore whether the temporal effect was due to perceptual filling-in of luminance information of the grid alley.

2 General method

2.1 *Observers*

Eight adults, including the author YA, participated as observers. All observers had normal or corrected-to-normal visual acuity. All observers, except the author YA, were unaware of the purpose of our experiments. All observers were trained using a peripheral field task based on a mapping method of the blind spot (Araragi and Nakamizo 2008). Written consent was obtained from all observers.

2.2 *Apparatus*
The stimuli were presented on a 21-inch CRT monitor (Trinitron GDM-F520, Sony). A computer (Vostro 220S, Dell) was used to control the presentation of the stimuli and to record responses that the observers made by pressing assigned keys. The observers' heads were held in position with a forehead-and-chin rest.

2.3 *Stimuli*
Figure 2a shows a typical example of the stimuli used in the present study. A white disc surrounded by a thin black circumference (hereafter called the 'disc' or the 'white disc') was presented or not presented on the stimulus configurations. In experiments 1 and 2, there were three configurations: intersection, alley, and background configurations, as shown in figure 2b. In the intersection configuration, the disc was presented at one of three intersections of the grey grid on the black background. In the alley configuration, the disc was presented 0.6 deg above or below an intersection of the grey grid on the black background. In the background configuration, the disc was presented on a homogeneous black or grey background, since the disc in the intersection or alley configuration was surrounded by the black square and grey alleys. In each experiment, the black and grey background conditions were counterbalanced. The retinal eccentricity of the disc was 6, 9, or 12 deg of visual angle[(1)] in the intersection and background configurations, and 5.4, 6.6, 8.4, 9.6, 11.4, or 12.6 deg in the alley configuration. The diameter of the disc was 0.6 deg. The width of the grid alley was 0.2 deg. The luminances of the white, grey, and black portions of the stimuli were 81.6, 43.7, and 6.2 cd m^{-2}, respectively.

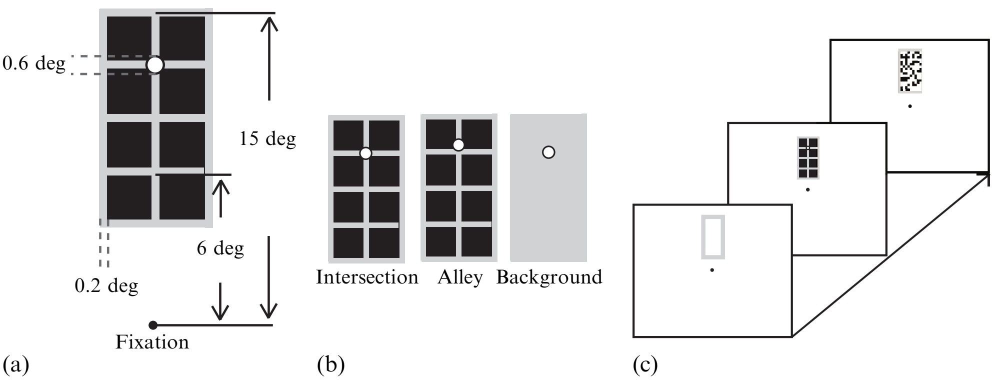

Figure 2. Typical stimuli in the present study. (a) A typical example of the stimuli in the 12 deg retinal eccentricity condition. (b) Stimuli in each stimulus configuration: intersection, alley, and background. (c) Schematic illustration of an experimental trial.

2.4 *Procedures*
The observers viewed the stimuli in a lit room with binocular vision. The light illuminating the apparatus was provided by six fluorescent ceiling lights. The luminous intensity at the top of the table on which the apparatus was placed was 510 lx. The viewing distance was 35 cm. An experimental trial consisted of three phrases as shown in figure 2c. In the first phase, a grey frame (6×12 deg) was presented 3 deg above

[(1)] The three retinal eccentricities were adopted on the basis of the results of a preliminary experiment. The results in the 200 ms stimulus duration and upper visual field condition and intersection configuration showed that, in the 6 deg retinal eccentricity condition, the disc was almost always perceived. In the 12 deg retinal eccentricity condition, the disc was hardly perceived, which would be due to 'ceiling effect'.

or below the fixation point at the centre of the screen. The observers were required to fixate on the fixation point, to pay attention to the inside of the grey frame, and to show the stimulus by pressing an assigned key on the keyboard when they felt ready. In the second phase, the stimulus was presented in the grey frame for a stimulus duration. The observers were required to continue to fixate steadily on the fixation point, to view the stimulus in peripheral vision, and to count the perceived white discs. In the third phase, after the stimulus presentation period, the stimulus was replaced by a random-dot pattern,(2) which was presented until the observers responded. The observers were required to report the number of perceived white discs at the end of the stimulus presentation period by pressing assigned keys.(3) After the response, the third phase and the experimental trial finished.

3 Experiment 1

The purpose of experiment 1 was to quantitatively examine the effects of stimulus duration and the retinal eccentricity of the disc on the extinction illusion. If the temporal effect of the extinction illusion occurred, it was predicted that the extinction probability when the stimulus duration was long would be higher than that when it was short.

3.1 *Methods*

The stimuli were presented for 120, 200, 480, 1000, 2000, 4000, or 6000 ms in only the upper visual field. Each observer completed two experimental sessions. An experimental session consisted of seven blocks (seven stimulus durations) of 48 trials [four conditions (three retinal eccentricity conditions + one no-disc condition) × three stimulus configurations × four repetitions]. Before each block, each observer performed several practice trials to get accustomed to the task at each stimulus duration. The order of the blocks in each session and the trials in each block were randomised for each observer.

3.2 *Results and discussion*

Results of experiment 1 are shown in figure 3. Figure 3a shows the means of no-disc responses, averaged over the eight observers and three retinal eccentricities, as a function of stimulus duration, separately for each stimulus configuration. No-disc response is defined as the probability that the disc was not perceived at the end of the stimulus presentation period when the disc was presented. A two-way repeated-measures ANOVA was performed on no-disc response with stimulus configuration (intersection, alley, background) and stimulus duration (120, 200, 480, 1000, 2000, 4000, 6000 ms) as main factors. The main effects of stimulus configuration and stimulus duration were significant ($F_{2,14} = 220.76$, $p < 0.01$; $F_{6,42} = 7.67$, $p < 0.01$). No-disc response was significantly higher in the intersection configuration than in the alley or background configuration. The interaction was significant ($F_{12,84} = 5.80$, $p < 0.01$). In the intersection configuration, the simple main effect of stimulus duration was significant ($F_{6,126} = 18.48$, $p < 0.01$). In the alley and background configurations, the simple main effects of stimulus duration were not significant ($F_{6,126} = 1.03$, $p > 0.05$; $F_{6,126} = 1.01$, $p > 0.05$), although no-disc responses were slightly increased in the 2000 – 6000 ms stimulus duration conditions. These results showed that the extinction illusion occurred in the intersection configuration. The means of probabilities of false alarms averaged

(2) The random-dot pattern was used to eliminate afterimages of the disc.

(3) The task indicated was to report whether or not a white disc was perceived at the end of the stimulus presentation period. Although the number of physical discs was one or zero, observers were allowed to report the presence of any number of discs to detect possible illusory discs. If the stimulus contained a white disc and the disc was not perceived at the end of the stimulus presentation period, it was considered as a single extinction event (a no-disc response). If a white disc was initially perceived, then disappeared and was not perceived at the end of the stimulus presentation period, a no-disc response was recorded.

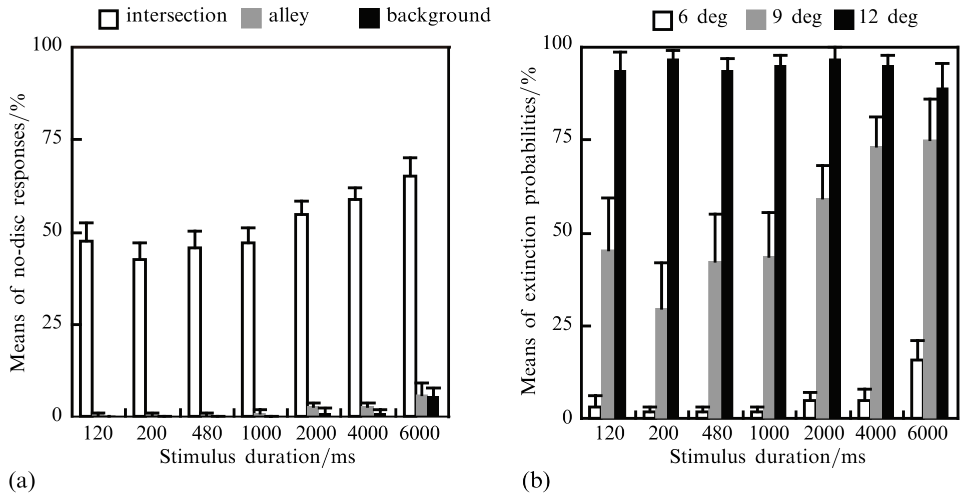

Figure 3. Results of experiment 1. (a) The means and standard errors of no-disc responses when a disc was presented, averaged over the eight observers and three retinal eccentricities, as a function of stimulus duration separately for each stimulus configuration. (b) The means and standard errors of the extinction probabilities, averaged over the eight observers, as a function of stimulus duration separately for each retinal eccentricity. The extinction probability was calculated as the subtraction of no-disc responses in the background configuration from those in the intersection configuration.

over the eight observers in the intersection (or alley) and background configurations in experiment 1 were 0.007 and 0, respectively. These means indicate that the observers were able to perform the task well.

Figure 3b shows the means of the extinction probabilities, averaged over the eight observers, as a function of stimulus duration, separately for each retinal eccentricity. The extinction probability, or the probability that the extinction illusion occurred, was calculated as the subtraction of no-disc responses in the background configuration (ie baseline)[(4)] from those in the intersection configuration, since those in the background configuration would be due to perceptual filling-in (ie perceptual fading or the Troxler effect). A two-way repeated-measures ANOVA was performed on extinction probability with stimulus duration (120, 200, 480, 1000, 2000, 4000, 6000 ms) and retinal eccentricity (6, 9, 12 deg) as main factors. The main effects of stimulus duration and retinal eccentricity were significant ($F_{6,42} = 6.13$, $p < 0.01$; $F_{2,14} = 78.62$, $p < 0.01$). The extinction probability increased as the retinal eccentricity of the disc increased. The interaction was significant ($F_{12,84} = 3.44$, $p < 0.01$). In the 9 deg retinal eccentricity condition, the simple main effect of stimulus duration was significant ($F_{6,126} = 11.23$, $p < 0.01$). The results of multiple-comparison tests showed significant differences between 120 – 4000, 120 – 6000, 200 – 2000, 200 – 4000, 200 – 6000, 480 – 4000, 480 – 6000, 1000 – 4000, and 1000 – 6000 ms stimulus duration conditions. These findings showed that the extinction probability increased as stimulus duration increased when the stimulus duration was over 1000 ms. In the 6 and 12 deg retinal eccentricity conditions, the simple main effects of stimulus duration were not significant ($F_{6,126} = 0.97$, $p > 0.05$; $F_{6,126} = 0.28$, $p > 0.05$).

The results of experiment 1 quantitatively showed the temporal effect of the extinction illusion, that is, the increment in the extinction probability dependent on stimulus duration. The results showed that (i) the extinction probability increased as stimulus duration increased when the stimulus duration was over 1000 ms, and (ii) the extinction probability

[(4)] A no-disc response in the background configuration was calculated as the average of those in the black and grey background configurations, since the difference between them was small.

was almost constant when the stimulus duration was 120 – 1000 ms (see Appendix). In the 9 deg retinal eccentricity condition, the temporal effect was significant. In the 6 and 12 deg retinal eccentricity conditions, the temporal effect was not significant, although the extinction probabilities in the 6 deg retinal eccentricity condition were slightly increased in the 2000 – 6000 ms stimulus duration conditions. The absence of significant effects would be due to floor and ceiling effects, respectively.

The results of experiment 1 support two previous reports. The present results in the alley configuration and binocular vision were consistent with the previous finding that the contrast sensitivity increased when the disc was slightly shifted from the intersection with dichoptic viewing (McAnany and Levine 2005). The present results in the 9 and 12 deg retinal eccentricity conditions support previous reports that the extinction illusion occurred regardless of stimulus duration (McAnany and Levine 2004, 2005).

The temporal effect of the extinction illusion would not be due to eye movements. If longer stimulus duration increased eye movements, then the extinction probabilities should decrease as stimulus duration increased. However, the results showed that the extinction probabilities increased as stimulus duration increased when the stimulus duration was over 1000 ms.

4 Experiment 2

The purpose of experiment 2 was to examine the effect of the visual field on the temporal effect of the extinction illusion in order to examine whether the temporal effect was due to attention or perceptual filling-in (hereafter the 'Troxler effect'). Experiment 1 quantitatively showed the temporal effect of the extinction illusion. The temporal effect might be due to attention and/or the Troxler effect. McAnany and Levine (2004) showed the upper – lower visual field anisotropy of the contrast sensitivity of the disc presented at the intersection of the grey grid on the black background. The contrast sensitivity of the disc presented in the upper visual field was lower than that in the lower visual field. In addition, previous studies have reported upper – lower visual field anisotropies of spatial resolution related to attention and the Troxler effect. He et al (1996) showed that the spatial resolution related to attention in the upper visual field was lower than that in the lower visual field. Sakaguchi (2003) suggested that the time required for the Troxler effect of the disc presented in the upper visual field was shorter than that in the lower visual field. If the temporal effect of the extinction illusion was due to the spatial resolution related to attention and/or the Troxler effect, it was predicted that the difference in the anisotropy of the extinction probability would become larger as stimulus duration increased.

4.1 *Methods*

The same eight observers that participated in experiment 1 also participated in experiment 2. The stimuli in experiment 2 were presented for 200 or 6000 ms in the upper or lower visual field. Each observer completed three experimental sessions. An experimental session consisted of four blocks (two stimulus durations $\times$ two visual fields) of 48 trials [four conditions (three retinal eccentricity conditions + one no-disc condition) $\times$ three stimulus configurations $\times$ four repetitions]. Before each block, each observer performed 10 practice trials to get accustomed to the task at each stimulus duration. The order of the blocks in each session and the trials in each block were randomised for each observer.

4.2 *Results and discussion*

Results of experiment 2 are shown in figure 4. Figure 4a shows the means of the extinction probabilities, averaged over the eight observers and three retinal eccentricities, as a function of stimulus duration, separately for each visual field. A three-way repeated-measures ANOVA was performed on extinction probability with stimulus duration (200, 6000 ms),

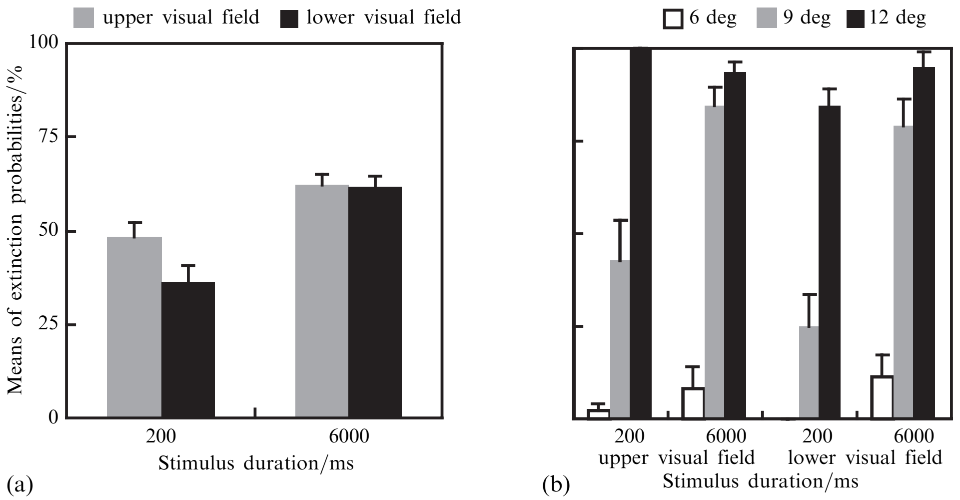

Figure 4. Results of experiment 2. (a) The means and standard errors of the extinction probabilities, averaged over the eight observers and three retinal eccentricities, as a function of stimulus duration separately for each visual field. (b) The means and standard errors of the extinction probabilities, averaged over the eight observers, as a function of stimulus duration and visual field separately for each retinal eccentricity. The mean of the extinction probability was 0 in the 200 ms stimulus duration, 6 deg retinal eccentricity, and lower visual field condition.

visual field (upper, lower), and retinal eccentricity (6, 9, 12 deg) as main factors. The main effects of stimulus duration and retinal eccentricity were significant ($F_{1,7} = 27.46$, $p < 0.01$; $F_{2,14} = 123.12$, $p < 0.01$). The extinction probability was higher in the 6000 ms stimulus duration condition than in the 200 ms stimulus duration condition. The main effect of visual field was not significant ($F_{1,7} = 3.14$, $p > 0.05$). The interactions between stimulus duration and visual field and between stimulus duration and retinal eccentricity were significant ($F_{1,7} = 10.04$, $p < 0.05$; $F_{2,14} = 28.77$, $p < 0.01$). In the upper and lower visual field conditions, the simple main effect tests showed that the extinction probability was significantly higher in the 6000 ms stimulus duration condition than in the 200 ms stimulus duration condition ($F_{1,14} = 11.16$, $p < 0.01$; $F_{1,14} = 37.17$, $p < 0.01$). In the 200 ms stimulus duration condition, the simple main effect test showed that the extinction probability was significantly higher in the upper visual field than in the lower visual field ($F_{1,14} = 9.26$, $p < 0.01$). On the other hand, in the 6000 ms stimulus duration condition, the difference in extinction probability between the upper and lower visual fields was not significant ($F_{1,14} = 0.01$, $p > 0.05$). These results showed an anisotropy of the extinction illusion in the 200 ms stimulus duration condition and an isotropy of the extinction illusion in the 6000 ms stimulus duration condition. The interactions between visual field and retinal eccentricity and between stimulus duration, visual field, and retinal eccentricity were not significant ($F_{2,14} = 1.55$, $p > 0.05$; $F_{2,14} = 0.44$, $p > 0.05$). The means of probabilities of false alarms averaged over the eight observers in the intersection (or alley) and background configurations in experiment 2 were 0 and 0, respectively.

The anisotropy of the extinction illusion in the 200 ms stimulus duration condition supports the visual field anisotropy found by McAnany and Levine (2004). They showed that when the lighter disc was presented at the intersection of the grey grid on the black background, the contrast sensitivity of the disc in the upper visual field was lower than that in the lower visual field. The reason for the anisotropy of the extinction illusion is not yet understood. Although Perry and Cowey (1985) reported that cone and ganglion densities were slightly greater in the lower visual field than in the upper visual field in the macaque monkey, the anisotropies were found in a more peripheral field than that corresponding to the stimuli presented in the present study.

The absence of visual field anisotropy in the 6000 ms stimulus duration condition was unlikely to be due to saturation of the extinction illusion or a faster Troxler effect in the upper field. As shown in figure 4a, in the 6000 ms stimulus duration condition, the extinction probabilities in the upper visual field condition did not differ from those in the lower visual field condition. On the other hand, the extinction probabilities were not high. Moreover, as shown in figure 4b, the extinction probabilities in the 6 deg retinal eccentricity condition were low.

The results in the 6000 ms stimulus duration condition suggest that the temporal effect of the extinction illusion was not due to the spatial resolution related to attention or the Troxler effect. Previous studies have reported the upper – lower visual field anisotropy of spatial resolution related to attention and the Troxler effect (He et al 1996; Sakaguchi 2003). If the temporal effect of the extinction illusion was due to spatial resolution related to attention and/or the Troxler effect, then the difference in the anisotropy of the extinction probability would become larger as stimulus duration increased. However, the results in the present study showed no significant difference in the 6000 ms stimulus duration condition, although a significant difference was shown in the 200 ms stimulus duration condition.

5 Experiment 3

The purpose of experiment 3 was to examine the effect of the length of the grid alley on the temporal effect of the extinction illusion in order to explore whether the temporal effect was due to perceptual filling-in of luminance information of the grid alley. Experiment 2 suggested that the temporal effect of the extinction illusion was not due to the spatial resolution related to attention or the Troxler effect. The temporal effect might be due to perceptual filling-in of luminance information of the grid alley. Previous studies have reported that when the length of line segments presented on opposite sides of the blind spot was longer than a certain critical length, perceptual completion or filling-in of the line at the blind spot occurred (Araragi and Nakamizo 2006; Araragi et al 2004; see also Araragi and Nakamizo 2008). Thus, if perceptual filling-in of luminance information of the grid alley generated the temporal effect, it was predicted that the temporal effect might depend on the length of the alley of the grid. That is, the temporal effect might occur when the alley of the grid is long, and might not occur when it is short.

5.1 *Methods*

Eight observers, including the author YA, participated in experiment 3. Seven of the eight observers that participated in experiments 1 and 2 also participated in experiment 3. The stimuli in experiment 3 were presented for 200 or 6000 ms in only the upper visual field. The whole length of a horizontal alley of the grid was 0, 1.8, 3.6, or 5.4 deg as shown in figures 5a and 5b. The whole length of a vertical alley of the grid was 12 deg, equal to that in experiments 1 and 2. Each observer completed three experimental sessions. An experimental session consisted of four blocks (two stimulus durations × two repetitions) of 40 trials [five conditions (four alley length conditions + one background condition) × four conditions (three retinal eccentricity conditions + one no-disc condition) × two repetitions]. Before each block, each observer performed 10 practice trials to get accustomed to the task at each stimulus duration. The order of the blocks in each session and the trials in each block were randomised for each observer.

5.2 *Results and discussion*

Figure 5c shows the means of the extinction probabilities, averaged over the eight observers and three retinal eccentricities, as a function of the alley length, separately for each stimulus duration. A three-way repeated-measures ANOVA was performed on extinction probability with stimulus duration (200, 6000 ms), alley length (0, 1.8, 3.6, 5.4 deg), and retinal eccentricity (6, 9, 12 deg) as main factors. The main effect of

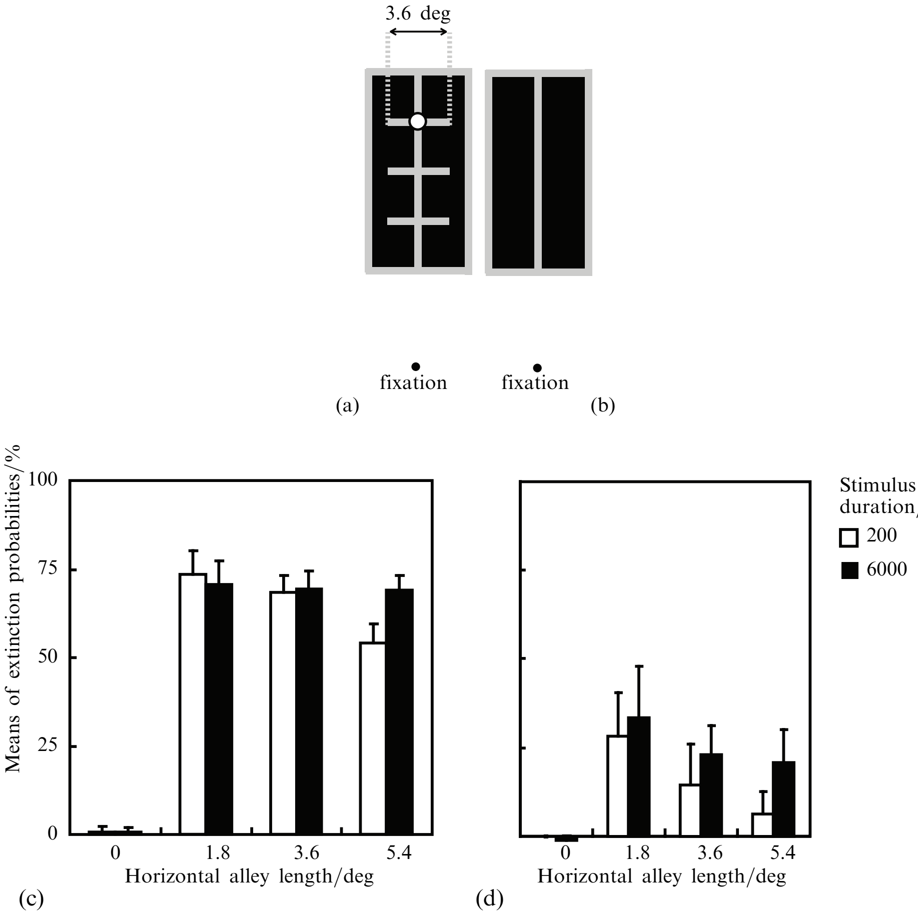

Figure 5. Stimuli and results of experiment 3. (a) Stimuli in the 3.6 deg horizontal alley length condition when the disc was presented, (b) stimuli in the 0 deg horizontal alley length condition when the disc was not presented. (c) The means and standard errors of the extinction probabilities, averaged over the eight observers and three retinal eccentricities, as a function of the horizontal alley length separately for each stimulus duration. (d) In the 6 deg retinal eccentricity condition, the means and standard errors of the extinction probabilities, averaged over the eight observers, as a function of the horizontal alley length separately for each stimulus duration.

stimulus duration was not significant ($F_{1,7} = 0.91$, $p > 0.05$). The main effects of alley length and retinal eccentricity were significant ($F_{3,21} = 177.28$, $p < 0.01$; $F_{2,14} = 77.47$, $p < 0.01$). The interactions between stimulus duration and alley length and between alley length and retinal eccentricity were significant ($F_{3,21} = 3.79$, $p < 0.05$; $F_{6,42} = 28.78$, $p < 0.01$). A simple main effect test showed that the extinction probability in only the 5.4 deg alley length condition was significantly higher in the 6000 ms stimulus duration condition than in the 200 ms stimulus duration condition ($F_{1,28} = 9.14$, $p < 0.01$). On the other hand, the extinction probabilities in the other alley length conditions were not significant (0 deg: $F_{1,28} = 0.00$, $p > 0.05$; 1.8 deg: $F_{1,28} = 0.32$, $p > 0.05$; 3.6 deg: $F_{1,28} = 0.05$, $p > 0.05$). That is, the temporal effect of the extinction illusion occurred only in the 5.4 deg alley length condition. In the 200 and 6000 ms stimulus duration conditions, the simple main effects of alley length were significant ($F_{3,42} = 105.45$, $p < 0.01$; $F_{3,42} = 113.03$, $p < 0.01$). The results of the multiple-comparison tests in the 200 ms stimulus duration condition showed significant differences between 0–1.8, 0–3.6, 0–5.4, 1.8–5.4, and 3.6–5.4 deg alley length conditions. On the other hand, the results in the 6000 ms stimulus duration condition showed significant differences between 0 – 1.8, 0 – 3.6, and 0 – 5.4 deg alley length conditions. The interactions between stimulus duration and retinal eccentricity and between stimulus duration, alley length, and retinal eccentricity were not significant ($F_{2,14} = 0.89$, $p > 0.05$; $F_{6,42} = 2.30$, $p > 0.05$). The means of probabilities of false alarms averaged over the eight observers in the intersection, 0 deg alley length, and background configurations in experiment 3 were 0, 0.010, and 0, respectively.

The results showed that the temporal effect of the extinction illusion occurred in only the 5.4 deg alley length condition. As shown in figure 5c, the temporal effect occurred when the alley was long, and did not occur when it was short. The 1.8 and 3.6 deg alley lengths might not be long enough for perceptual filling-in of luminance information of the grid alley to occur. On the other hand, the 5.4 deg alley length might be longer than the critical length for perceptual filling-in of luminance information of the grid alley to occur. Therefore, these results suggest that the temporal effect might be due to perceptual filling-in of luminance information of the grid alley.

The absence of the temporal effect in the short alley conditions was not due to saturation of the extinction illusion. As shown in figure 5c, the extinction probabilities in the 200 ms stimulus duration and short alley conditions were high, and did not differ from those in the 6000 ms stimulus duration condition. On the other hand, as shown in figure 5d, the extinction probabilities in the 6 deg retinal eccentricity condition were low, and showed that the temporal effect occurred slightly in the short alley conditions. Moreover, the temporal effect increased as the alley length was longer, although there were no significant differences.

The results in the 200 ms stimulus duration condition showed that the extinction probabilities in the 1.8 and 3.6 deg alley length conditions were significantly higher than that in the 5.4 deg alley length condition. There are two possible interpretations for this phenomenon. One interpretation is that the extinction illusion occurred more frequently in short alley condition than in long alley condition, possibly because of stimulus complexity or crowding by the ends of the alley in the short alley conditions. Since the ends of the alley in the short alley conditions were near the disc, these ends might have prevented the disc from being perceived. An alternative interpretation is that the extinction illusion occurred less frequently in long alley condition than in short alley condition, but the possible reasons of this interpretation are unclear. If perceptual filling-in of luminance information of the grid alley generated the phenomenon, then the extinction illusion would be expected to occur more frequently in long alley condition than in short alley condition. This phenomenon would suggest that the extinction illusion in the 200 ms stimulus duration condition was not due to perceptual filling-in of luminance information of the grid alley. Therefore, it is unclear whether the phenomenon is based on a property of the extinction illusion.

The results suggest that the temporal effect of the extinction illusion would not be due to eye movements. If eye movements occurred more easily in the 200 ms stimulus duration condition than in the 6000 ms stimulus duration condition, then the extinction probability would not change depending on the alley length in the 200 ms stimulus duration condition. However, the results showed that the extinction probabilities in the short alley conditions were higher than that in the long alley condition.

6 General discussion

The present study quantitatively showed the temporal effect of the extinction illusion, or the increment in the extinction probability dependent on stimulus duration. Experiment 1 showed that the extinction probability increased as stimulus duration increased when the stimulus duration was over 1000 ms, and as the retinal eccentricity of the disc increased. Experiment 2 showed that when the stimulus duration was 200 ms, the extinction probability was higher in the upper visual field than in the lower visual field;

there was no anisotropy when the stimulus duration was 6000 ms. Experiment 3 showed that when the alley was long, the extinction probability was higher in the 6000 ms stimulus duration condition than in the 200 ms stimulus duration condition; there was no temporal effect when the alley was short. These results suggest that the temporal effect might be due to perceptual filling-in of luminance information of the grid alley.

The temporal effect of the extinction illusion would not be due to eye movements. If longer stimulus duration increased eye movements, then the extinction illusion should decrease as stimulus duration increased. However, the results of experiment 1 showed that the extinction illusion increased as stimulus duration increased when the stimulus duration was over 1000 ms. On the other hand, if eye movements occurred more easily in the 200 ms stimulus duration condition than in the 6000 ms stimulus duration condition, then the extinction probability would not change depending on the alley length when the stimulus duration was 200 ms. However, the results of experiment 3 showed that the extinction probability was higher in the short alley conditions than in the long alley condition.

The results of experiment 3 suggest that the temporal effect of the extinction illusion might be due to perceptual filling-in of luminance information of the grid alley. The results showed that the temporal effect occurred when the alley was long, and did not occur when it was short. The 1.8 and 3.6 deg alley lengths might not be long enough for perceptual filling-in of luminance information of the grid alley to occur. On the other hand, the 5.4 deg alley length might be longer than the critical length for perceptual filling-in of luminance information of the grid alley to occur. Moreover, experiment 3 showed that, in the 200 ms stimulus duration condition, the extinction probability when the alley was short was higher than that when the alley was long. This suggests that the 200 ms stimulus duration might not have been long enough for perceptual filling-in of luminance information of the grid alley to occur.

The present study suggests that the extinction illusion is based on dual-stage processing with regard to stimulus duration. Experiment 1 showed that the extinction illusion increased as stimulus duration increased when the stimulus duration was over 1000 ms. Moreover, the extinction illusion occurred when the stimulus duration was under 1000 ms. These results indicate two different stages in processing of the extinction illusion between under and over 1000 ms stimulus duration conditions. When the stimulus duration was over 1000 ms, perceptual filling-in of luminance information of the grid alley might have generated the increment of the extinction illusion, since experiment 3 showed that the temporal effect of the extinction illusion occurred when the alley was long, and did not occur when it was short. On the other hand, when the stimulus duration was under 1000 ms, perceptual filling-in of luminance information of the grid alley might have not generated the extinction illusion, since experiment 3 showed that the extinction probability in the 200 ms stimulus duration condition was higher when the alley was shorter. Although the reason for the extinction illusion in under 1000 ms stimulus duration was unclear in the present study, it might be related to stimulus complexity (Levine and McAnany 2008).(5) Therefore, these results in the present study suggest that the extinction illusion is based on dual-stage processing. In other words, when the stimulus duration is less than 1000 ms, stimulus complexity might generate the extinction illusion. On the other hand, when the stimulus duration is more than 1000 ms, perceptual filling-in of luminance information of the grid alley might generate the increment of the extinction illusion.

(5) Levine and McAnany (2008) proposed stimulus complexity as a possible reason for decrement of the contrast sensitivity of the disc as the curvature of the grid increased. The extinction illusion occurred in grids consisting not only of straight lines but also of sine-waves (Howe and Livingstone 2007; Levine and McAnany 2008). Levine and McAnany (2008) showed that the contrast sensitivity of a lighter or darker disc presented at the intersection of the grey grid on the black background decreased as the curvature of the grid increased.

The dual-stage processing of the extinction illusion suggested by the present study differs from that proposed by McAnany and Levine (2005). They examined whether the extinction illusion was due to a pre-fusion mechanism and/or a post-fusion mechanism with dichoptic viewing. Their results indicated that both pre- and post-fusion processing contributed to the extinction illusion. They proposed a dual-stage theory of the extinction illusion; the first stage (pre-fusion mechanism) was based on lateral antagonism. On the other hand, they did not propose a specific cortical mechanism for the second stage (post-fusion mechanism). Perceptual filling-in of luminance information of the grid alley in the present study would correspond to a cortical mechanism of the extinction illusion. On the other hand, when the stimulus duration was 120 – 1000 ms, the stimulus information would reach the visual cortex. Therefore, the extinction illusion in the 120 – 1000 ms stimulus duration in the present study would be processed in the second stage (ie cortical mechanism) of the extinction illusion proposed by McAnany and Levine (2005), which was not due to perceptual filling-in of luminance information of the grid alley. There might be two cortical mechanisms in the second stage (post-fusion mechanism) proposed by McAnany and Levine (2005). Thus, the dual-stage processing of the extinction illusion suggested by the present study does not conflict with that proposed by McAnany and Levine (2005).

We speculate that the extinction illusion consists of triple-stage processing: a pre-fusion stage (retina or lateral geniculate nucleus; LGN), a post-fusion stage without perceptual filling-in (cortex), and a post-fusion stage with perceptual filling-in (cortex). Previous studies (Levine and McAnany 2008; McAnany and Levine 2005) and the present study suggest that retinal antagonism, stimulus complexity, and/or perceptual filling-in of luminance information of the grid alley might generate or facilitate the extinction illusion at each stage. The triple-stage processing hypothesis of the extinction illusion awaits further studies.

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Appendix

According to Ninio (personal communication), there are possible kinetic processes, which are solid foundations in chemistry and physics. Suppose that a white disc had two states, visible and invisible. The simplest model for a transition between the two states is one in which there is a constant probability per unit time for a disc switching from visibility to invisibility: $(\mathrm{d}x)/x = -k(\mathrm{d}t)$. Wherein, using the empirical extinction probabilities collected in the 120 – 6000 ms stimulus duration conditions, the regression line for visibility in each retinal eccentricity was calculated for 6 deg as $x = -0.022t + 4.599$, $R^2 = 0.79$, for 9 deg as $x = -0.172t + 4.132$, $R^2 = 0.91$, and for 12 deg as $x = -0.105t + 1.425$, $R^2 = 0.29$. In this formula, x means the natural logarithm visible responses {ie ln [100%-extinction probability (%)]}. In the 12 deg retinal eccentricity condition, the R^2 value of the regression line was very low. It would be due to a ceiling effect, since the no-disc response was 100% in the intersection configuration and 6000 ms stimulus duration condition. On the other hand, in the 6 and 9 deg retinal eccentricity conditions, the R^2 value of the regression line was high. The results suggest a mixture of the two positive states, visible and invisible. In addition, the regression lines for invisibility were calculated for 6 deg as $x = 0.341t + 0.516$, $R^2 = 0.80$, and for 9 deg as $x = 0.130t + 3.662$, $R^2 = 0.76$. In this formula, x means the natural logarithm invisible responses {ie ln [extinction probability (%)]}. This indicates that the time required for 100% extinction probability was approximately 12 000 and 7300 ms in the 6 and 9 deg retinal eccentricity conditions, respectively. Further study might be required to examine the extinction probability in over 12 000 ms stimulus duration condition.

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