Disappearance elicited by contrast decrements

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The observation that physically present visual stimuli can sometimes disappear from consciousness has intrigued vision scientists for centuries. Two situations are known to cause such disappearance: stationary peripheral images and images (centrally or peripherally viewed) masked by abrupt contrast increments of stimuli in adjacent retinal areas. Both of these situations require near-image stabilization on the retina. Here, we describe a third way to remove stimuli from conscious awareness. It involves *contrast decrements* (CDs) of nearly stabilized images in the periphery. Unlike the Troxler effect, with sufficient CD, complete disappearance can be achieved almost instantaneously without significant adaptation periods. Unlike traditional masking effects, CD disappearance does not result in an after-image at or near the locus of stimulation. We report the results of four experiments in which some of the characteristics of this newly discovered phenomenon were examined. The results indicate that CDs produced by changes in the luminance of the target (see Experiment 2) or by changes in background luminance (see Experiment 3) result in an immediate loss of sensitivity to stimuli that would take much longer to fade with Troxler-like adaptation (see Experiment 1). However, the duration of such loss of sensitivity (~2 sec) is comparable for the two paradigms. The frequency of disappearance increased with greater contour eccentricity, but disappearance duration remained fairly constant.

Troxler (1804) noted that peripheral stimuli, viewed under conditions approximating retinal image stabilization, gradually fade and disappear (in part or in whole) after some time (~8–14 sec). More sophisticated image stabilization techniques (Burbeck & Kelly, 1984; Olson, Tulunay-Keeseey, & Saleh, 1993; Tulunay-Keeseey, 1982) result in similar stimulus fading, even when stimuli are viewed in the central retina. Once a stimulus has disappeared under these stabilized conditions, any movement of the stimulus relative to the retina causes reappearance. The most popular explanation for these phenomena involves the notion that disappearance is caused by local adaptation and reappearance occurs because of inadvertent eye movements that expose unadapted retinal areas.

Another way to remove stimuli from consciousness involves visual masking. Traditionally, this phenomenon has been investigated by the presentation of targets and masking stimuli for brief periods while relative time (interstimulus interval [ISI] or stimulus onset asynchrony [SOA]) and order of presentation (e.g., paracontrast or metacontrast) are varied. However, one study (Breitmeyer & Rudd, 1981) also demonstrated that a continuously viewed stimulus can be abruptly removed from conscious awareness by the brief presentation of nearby masking stimuli. This implies that disappearance need not involve local adaptation. However, in these situations, the masking stimuli can sometimes result in an af-

terimage that continues to convey the retinal locus of the masked stimulus.

We discovered that a peripherally viewed stimulus (under steady fixation conditions) disappears from view without an afterimage when its contrast is abruptly decreased. The disappearance is abrupt and complete and lasts for about 2 sec.¹ This technique provides investigators with a way to abruptly remove stimuli from conscious awareness without using a second, spatially distinct stimulus. This provides a technique that can be used to address many issues concerned with implicit visual processing.

EXPERIMENT 1 Troxler Fading

Method

Subjects. The authors served as subjects in all four of the experiments reported here. Two subjects were male (J.M., age 60 years, and K.T., age 24 years) and the other female (M.F., age 29 years). M.F. was initially naive as to the hypothesis under investigation. All of the subjects had visual acuity corrected to 20/20. Informed consent and subject protection was in adherence with NIH guidelines.

Procedure. In this experiment, two sequential frames were used to gather baseline data on the Troxler effect. Both were presented on a computer display² and subtended 30.5° (width) × 20.8° (height) of visual angle (VA). The background luminance was the same for both stimuli (57.0 cd/m²).³ The first frame contained only a centrally located circular fixation target (VA = 7° in diameter; 2.0 cd/m²). In the second frame, an ellipsoid disk (VA = 6.1° in width × 4.8° in height), the left edge of which was located 8.0° to the right of fixation, was added. The luminance of the disk in the second frame was lighter or darker than the background and varied in luminance (lighter = 69.0, 62.0, and 58 cd/m²; darker = 38.0, 43.0, and 46.0 cd/m²). The contrasts between these disks and the

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background [$C = (L_{\max} - L_{\min}) / (L_{\max} + L_{\min}) \times 100$, where $L_{\max}$ is the maximum luminance and $L_{\min}$ is the minimal luminance] were 10.0%, 4.0%, and 0.8% for the lighter disks and 20.0%, 14.0%, and 11.0% for the darker disks. On a given trial, the subjects viewed the fixation point alone for 1.0 sec, and then one of the comparison stimuli was presented. The subjects indicated the advent of complete stimulus disappearance with one keystroke and the advent of the reappearance of any part of the disk with the stroke of another key.⁴ The time was measured (in milliseconds) from stimulus onset until the subject indicated complete disappearance, and disappearance duration was measured from the first keystroke (disappearance) to the second (reappearance). The next trial was initiated as soon as the subject indicated reappearance. The order of light and dark disk conditions and contrast decrement (CD) levels was randomized across trials. At least 48 trials were completed for each condition. All viewing was binocular from a distance of 50 cm.

Results and Discussion

The results of this experiment, involving time to disappearance (incubation time) and disappearance duration, are presented in Figure 1. Time to disappearance was 6 sec or more for all but the disk with the lowest contrast (0.8%). The disappearance duration for all but the disk of lowest contrast was in the range of 0.5–2.0 sec. These results are in general agreement with those of previous studies of the Troxler effect (Cibis, 1948; Cibis & Müller, 1948; Clarke, 1957, 1960, 1961), in which the disappearance was considered to be due to local adaptation in the specific retinal area stimulated. The major conclusion of this study is that, for the higher contrast

stimuli, it takes a considerable time for disappearance to occur. All 3 subjects agreed that under these conditions the stimuli never disappeared immediately upon presentation. The simplest notion of adaptation (e.g., Corso, 1967) is that of a loss of sensitivity with exposure to an unchanging stimulus. A model that posits such simple passive decay of luminance sensitivity (e.g., photo pigment bleaching) could account for the incubation time, and the loss of retinal stabilization is adequate to explain reappearance. The reappearance times according to this notion would suggest that most observers can only maintain fixation for less than 2 sec.

EXPERIMENT 2 Disk Changes

Method

Subjects. The subjects were the same as in Experiment 1.

Procedure. In the second experiment, each trial involved the abrupt transition from a standard image to a comparison image. Both images contained an ellipsoid disk ($VA = 6.1^\circ$ in width and 4.8° in height), the left edge of which was located 8° to the right of the fixation point. The background luminance of both the standard and the comparison was held constant at 57 cd/m², and the luminance of the standard disk was either 30.0 ($C = 31\%$) or 93.0 cd/m² ($C = 24\%$). The luminance of the comparison disks was varied to produce different levels of CD when the two images were interchanged. CDs were produced in two ways: by increasing the luminance of a disk that was darker than the background (darker disk) and by decreasing the luminance of a disk that was lighter than the

Figure 1. Incubation time (upper panel) and disappearance duration (lower panel) as a function of contrast for light (open symbols) and dark (closed symbols) disks for each observer. In this and all subsequent figures, vertical bars = ± 1.0 SE. If the error bars are not apparent, they are subsumed by the size of the symbols.

background (lighter disk). For the darker comparison disks, the luminance values were 33.0%, 38.0%, 43.0%, and 46.0 cd/m² ($C = 27.0\%$, 20.0% , 14.0% , and 11.0% , respectively). When the comparison disk replaced the standard, the resultant CDs $\{[(\text{standard disk contrast} - \text{comparison disk contrast}) / \text{standard disk contrast}] \times 100\}$ were 12.9%, 35.5%, 54.9%, and 64.5%, respectively. For the lighter comparison disks, the luminance values were 76.0, 69.0, 62.0, and 58 cd/m² ($C = 14.0\%$, 10.0% , 4.0% , and 0.8% , respectively). When the comparison disk replaced the standard, the resultant CDs were 42%, 58%, 83%, and 96%, respectively. Each trial began with the same fixation stimulus that was used in Experiment 1 (1.0 sec), followed by the standard image containing the fixation point and one of the standard disks for 3.5 sec, and then by a comparison image containing one of the comparison disks, which was terminated when the subject responded (see Figure 2). A 100-msec, 750-Hz tone was presented at the onset of the third stimulus. The order of light and dark disk conditions and CD levels was randomized across trials. The subjects were instructed to report whether the disk disappeared completely at the sound of the tone and, if so, for how long. They used two response keys: one to indicate that the disk had not disappeared, and the other to indicate that it had. The second keypress was delayed until the disk reappeared to indicate the duration of disappearance. The time from CD until the depression of the reappearance key was recorded in milliseconds. At least 72 trials were completed for each condition. The criterion for disappearance was the complete disappearance of the entire stimulus, and the criterion for reappearance was the reappearance of any part of the stimulus.

Results and Discussion

The results of this experiment are presented in Figure 3. It is apparent that the duration of disappearance (upper panels, open and closed circles) is quite stable for all 3 subjects across all but the highest CD.⁵ The frequency of disappearance increased as CD increased (Figure 3, bottom panels, open and closed circles) for all 3 observers. The major finding of this experiment is that

for all but the lowest CDs, the proportion of times that disappearance occurred is quite high for all 3 observers. The reader should note that for the highest CDs the final disk contrasts matched those used in Experiment 1. So, whereas the 0.8% contrast disk used in Experiment 1 faded (at least partially) in less than 3.5 sec, the higher contrast disks did not fade for at least 6 sec. In Experiment 2, however, CD produced a high probability of disappearance for the higher contrast stimuli. It should also be noted that if the target did not disappear immediately, it was tabulated as a trial on which disappearance did not occur, so all trials on which disappearance occurred included immediate disappearance.

Two reviewers of the manuscript felt that the disappearance observed in this experiment could have involved adaptation effects, since our standard stimulus was presented for 3.5 sec. To test this notion, all 3 observers repeated Experiment 2 with only 500-msec presentations of the standard prior to CD. If CD disappearance interacted with adaptation, then the frequency and duration of disappearance would be expected to be less for this shortened adaptation time. These results have been added to Figure 3 (open and closed squares). It is apparent that a shorter adaptation time had little effect on disappearance duration (and actually increased it for Subject K.T.), but did reduce the frequency of disappearance somewhat, especially for the lighter disks. Thus, adaptation time does interact with CD, but this effect is not large. The proportion of disappearance is, for the most part, not consistent with a passive decay model in that disappearance is immediate in comparison with the much longer incubation times found in Experiment 1.

Figure 2. A depiction of the frame sequences in Experiment 2. F1–F3 are the 3 frames used. T1–T2 were 1.0 and 3.5 sec in duration, respectively. T3 lasted until the subject responded.

DISK CHANGES (EXPERIMENT 2)

Figure 3. Disappearance duration (upper panel) and proportion of disappearance (lower panel) as a function of contrast for light (open symbols) and dark (closed symbols) disks for each observer. Circles represent 3.5-sec adaptation durations, and squares represent 0.5-sec adaptation durations.

EXPERIMENT 3 Background Changes

Method

Subjects. The subjects were the same as in the previous experiments.

Procedure. In the third experiment, in order to produce different CDs, the background, rather than the disk, was varied systematically. The disk luminance was held constant at 57 cd/m², and the luminance of the background was either 30.0 or 92.0 cd/m². CDs were produced in two ways: by increasing the luminance of the background that was darker than the disk (dark background) and by decreasing the luminance of the background that was lighter than the disk (light background). The same levels of luminance were used for the backgrounds in Experiment 3 as for the disks in Experiment 2. Therefore, the same CD percentages were produced for the dark and light backgrounds as for the dark and light disks in Experiment 2. The order of light and dark background conditions and CD levels was randomized across trials. All other details were the same as Experiment 2.

Results and Discussion

The results of Experiment 3, involving CDs produced by changes in background luminance, are presented in Figure 4. These results are similar to those of Experiment 2 for all 3 observers. Together, Experiments 2 and 3 indicate that it is the CD, and not just luminance changes per se, that leads to disappearance. These data also make it clear that disappearance is not due to local adaptation, because it is the change in luminance in the background that is associated with immediate disappearance.

EXPERIMENT 4 Eccentricity Effects

Since both the Troxler effect (Clarcke, 1957, 1961) and visual masking (Breitmeyer & Rudd, 1981) increase with eccentricity, we examined the effect of this variable with CD in Experiment 4.

Method

Subjects. The subjects were the same as in the previous experiments.

Procedure. The background luminance was set to 57 cd/m², and pairs of centrally located square targets were presented. The first target was set to 30 cd/m² ($C = 31\%$) and the second to 43 cd/m² ($C = 14\%$), resulting in a CD of 54.8%. Six pairs of square targets, with sides subtending 2°, 4°, 6°, 7.5°, 9.5°, and 11.5° of visual angle, were used. Whereas the stimuli were centered on the fixation point, the edges that defined the squares were systematically more peripheral, with eccentricities of 1°, 2°, 3°, 3.75°, 4.75°, and 5.75°, respectively. The subjects responded as in Experiment 2, and at least 48 trials were completed for each eccentricity.

Results and Discussion

The results of Experiment 4, involving CDs at various eccentricities, are presented in Figure 5. The duration of disappearance was fairly stable across eccentricities for 2 observers (J.M. and M.F.) but increased with eccentricities for Observer K.T. The proportion of disappearance increased with eccentricity for all 3 observers, but this increase saturated at eccentricities of 3° and above for Observers J.M. and K.T.

Figure 4. Disappearance duration (upper panel) and proportion of disappearance (lower panel) as a function of contrast for light (open symbols) and dark (closed symbols) backgrounds for each observer.

GENERAL DISCUSSION

In a comparison of the disappearance in the CD experiments with that found in Troxler's (1804) experiment, all 3 observers noted that both the traditional Troxler paradigm and the CD paradigm resulted in disappear-

ance, but CD caused immediate and complete disappearance as opposed to the much slower, more gradual, and often partial disappearance in the Troxler paradigm. We have asked numerous individuals to compare the two situations informally, and they all have concurred with this observation. CD disappearance is equally apparent

Figure 5. Disappearance duration (upper panel) and proportion of disappearance (lower panel) as a function of eccentricity of the edges of the squares, for each observer.

whether the CD is caused by changes in the disk luminance (as in the second experiment reported here) or by changes in the background luminance when the disk luminance is held constant (as in Experiment 3). We have never observed disappearance with increases in contrast. Informal observations suggest that any change in the spatial location, shape, or content of the stimulus (all of which involve contrast increments) coincident with CD prevents disappearance. Similarly, if the contrast reduction is more than 100% (i.e., if it results in contrast reversal), disappearance does not occur.

What is surprising about this finding is that most stimuli that are viewed under stabilized conditions result in a clear and distinct afterimage when they are abruptly removed. The afterimage provides a spatial marker, indicating the previous shape and retinal locus, which can last for numerous seconds after stimulus termination. With disappearance produced by CD, the stimulus is still physically present, but shape and spatial location information are abruptly removed from conscious awareness. If a stimulus is completely removed after it has disappeared, a distinct afterimage is produced.

Hood and Finkelstein (1986) reviewed various models of adaptation and concluded that simple passive models of luminance adaptation are not adequate to account for sensitivity changes measured with stimulus detection techniques. The threshold for the detection of a brief target on a briefly flashed adapting field was elevated by almost 2 log units in comparison with thresholds obtained on an extended (i.e., continuous) duration adapting field. Snowden (2001) used stimulus detection measures and measured the threshold for a brief test flash presented at different times during the presentation of a 400-msec adapting pedestal of background luminance. Thresholds were significantly higher when the brief test was presented near the onset or offset of the adapting field than when the test flashes were presented at 100 or 200 msec relative to pedestal onset. He suggested that it was the transient activity at onset and offset that accounted for this loss of sensitivity and showed that sensitivity was elevated throughout the duration of the pedestal when the adapting field was flickered at a rate of 16 Hz. The present results are similar to Snowden's in that CD resulted in a loss of sensitivity for a stimulus presented coincident with adapting field offset, but it is difficult to directly compare the results, because in the present experiment we used extended duration "test" stimuli, whereas Snowden used brief presentations. The transients that occurred at the onset and offset of his test stimuli may have led to increased detection of his stimuli in comparison with that of our longer stimuli.

The present results are also similar to those of some previous masking studies in which spatially overlapping stimuli were used. Weisstein (1971) has shown that U-shaped metacontrast masking can occur, particularly for dichoptically presented target and mask stimuli that consist of overlapping disks. She varied the energy of the spatially larger masking disks and found differences in

the masking functions. It is not clear whether the masking observed was due to the onset and/or offset of the mask. Similar masking was obtained dichoptically by stimulus offset (Breitmeyer & Kersey, 1981). However, the target contrast (75%) was greater than the mask contrast (25%), and the smallest ISI used was 15 msec. The subjects rated the contrast reduction of the target as greatest at an ISI of 15 msec, but it is unclear whether this target contrast reduction ever resulted in complete target disappearance. Breitmeyer and Kersey argued that it was the offset of the mask that terminated the visible persistence of the target in a metacontrast paradigm. Macknik and Livingstone (1998) have shown that stimulus parameters that produce forward masking (in which the mask precedes the target) suppress the transient on-response to the target in monkey visual cortex. Those parameters that produce backward masking (in which the mask comes after the target) inhibit the transient after-discharge, the excitatory response that occurs just after the offset of the target. In all three of these studies, the target was presented briefly. In the present investigation, the target was continuously present but not visible for a considerable length of time. If the first stimulus (which was always of higher contrast) is considered the mask, then our paradigm must be considered one of forward masking. According to Macknik and Livingstone, what led to disappearance in the present study was the offset transient of the "mask" (the first stimulus in Experiments 2–4 of the present study), which inhibited the onset transient normally produced by the "target" (the second stimulus).

This phenomenon raises many interesting questions concerning human perceptual processes that might be addressed in future experiments. Do the mechanisms that subserve such disappearance reside in the retina or at higher levels in the processing stream? Although the requirement of steady fixation might suggest that this phenomenon is retinally based, a recent study (Stürzel & Spillmann, 2001) with textured surfaces has demonstrated that such structured stimuli fade from consciousness when viewed against similarly structured backgrounds, suggesting cortical involvement. Will spatial or temporal filtering alter this effect? Peripheral targets with blurred edges fade more quickly in a Troxler paradigm, and it might be expected that gradual contrast reduction might allow the target to remain within consciousness until contrast threshold is reached. Are attentional processes released from a location when a target disappears without an afterimage? Can a target that has disappeared phenomenally provide unconscious information to various action systems that mediate eye, head, and limb movements? Even when a target disappears from consciousness without an afterimage, do we still know where it is located? Does CD result in a transient loss in contrast sensitivity in local areas? Does reappearance depend on fixation stability, or does it involve a relatively constant recovery time? The masking literature suggests that reappearance occurs after recov-

ery from inhibition, but stabilized image studies suggest that eye movements that result in effective contrast increments cause reappearance.

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NOTES

1. The reader may experience this disappearance and reappearance phenomenon with any computer program that allows rapid transition between graphics images. We have used Microsoft PowerPoint in numerous demonstrations.
2. The images were displayed on a high-resolution Sony (PVM-1343MD) monitor. Stimulus presentation was controlled with a Data Translation image-processing system (Model DT2861). Images were constructed with custom-written software.
3. A Tektronix Photometer (Model J17) with a luminance probe (Model J1803) was used to measure local luminance.
4. The use of a manual response to estimate incubation time and duration of disappearance is, of course, contaminated by reaction time limits and variability. This contamination might be expected to be less of a factor for longer time estimates.
5. The highest CD resulted in a comparison disk that had a contrast quite close to the threshold for the detection of that stimulus at that eccentricity when it was presented alone. All 3 observers felt that they could not be confident of their ability to hold steady fixation in the face of these long disappearance times and were concerned that reappearance might have been due to inadvertent loss of fixation.

(Manuscript received June 29, 2002;
revision accepted for publication January 28, 2003.)