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Research Note

An Adaptation-Induced Pop-Out in Visual Search

JAN THEEUWES,*† MARCEL P. LUCASSEN*‡

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The present study demonstrates that an object embedded in an array of identical objects can pop-out. Dependent on the stimuli preceding the search display, local (chromatic) adaptation causes an identical object to pop-out because it appears to have a colour (Expt 1) or brightness (Expt 2) that is slightly different from the colour and brightness of the other objects in the display. Experiment 3 shows that this pop-out even occurs when the stimulus preceding the search display is presented for only 100 msec.

Visual search   Pop-out   Pre-attentive vision   Chromatic adaptation   Colour afterimage

INTRODUCTION

If a single red object is embedded in an array of green objects, it is seen immediately without effort; a phenomenon known as visual "pop-out" (Treisman & Gelade, 1980). One can speak of a "pop-out" when the time to detect the object is hardly affected by the number of elements in the display [< 5 or 6 msec per item (Treisman & Souther, 1985)]. The object with a unique feature is detected through early, spatially parallel and automatic encoding, and its presence tends to call attention to itself (Treisman & Gormican, 1988). The calling of attention is the basis for the pop-out phenomenon (Treisman, 1988), and suggests that a pop-out is always mediated by an *automatic* shift of spatial attention to the location containing the unique feature (Hoffman, Nelson & Houck, 1983). This type of processing is contrasted with detection tasks in which the time to find the object linearly increases with the number of elements in the display, suggesting spatially serial search. The early perceptual encoding causing an object to pop-out from its background is limited to a particular set of primitive features, such as orientation of edges, colour, brightness, shape, etc.

The present study demonstrates a new pop-out phenomenon based on a well-known physiological mechanism, usually referred to as *local (chromatic) adaptation*. An object embedded in an array of *identical* objects pops-out, because temporarily it appears to have a colour (chromatic pop-out; Expt 1) or brightness (achromatic pop-out; Expt 2) that is slightly different from the colour or brightness of the other objects. The object *appears* to be different because it is the only object being presented at a retinal location that is more or less adapted to the colour and brightness of the preceding masking stimulus. Experiment 3 investigates the time–course of the chromatic and achromatic adaption-induced pop-out effect; how long the adaptation time must be in order to obtain the pop-out effect.

Obviously, in all circumstances the eyes are subject to the process of local (chromatic) adaptation, resulting in an after-image that may or may not become visible. Daw (1962) discussed why after-images are not seen in normal circumstances. He argued that "as we move the eye around the scene, the after-image stays with it, invisible and intact, in spite of all the other impressions made on the retina". He pointed out the importance of contours for "the after-image may re-appear when the eye is rotated to a position in which the after-image is in geometric registry with the scene which originally produced it". Also in the laboratory after-images play a role in any task requiring visual processing; yet, the effect it may have on the performance may be negligible or unimportant. The present study demonstrates, however, that under particular circumstances (local) adaptation may completely change the outcome of certain experiments. Although it has been shown that strong and vivid after-images occur after a (relatively) long exposure to a (bright) stimulus (Brown, 1965), the present study shows that local (chromatic) adaptation may cause subtle and rapidly occurring changes in the visual percept, which may radically change the results of a simple visual search task.

METHOD

Experiment 1: chromatic pop-out

Subjects. Two experienced observers (the authors) participated in all experiments. Both had corrected-to-normal acuity and reported having no colour defects as confirmed by the standard colour vision tests.

*TNO Institute for Perception, P.O. Box 23, 3769 ZG Soesterberg, The Netherlands.
†To whom all correspondence should be addressed.
‡Present address: Colour Matching Department, AKZO Coatings B.V., Sassenheim, The Netherlands.

Apparatus and stimuli. A NEC Multisync 3D VGA colour CRT (resolution 640 × 350 pixels) controlled by SX-386 personal computer (G2) was used for presenting the stimuli. The computer controlled the timing of the events, generated pictures and recorded reaction time. The "/"-key and the "z"-key of the computer keyboard were used as response buttons. Each subject was tested in a sound-attenuated, dimly-lit room, his head resting on a chinrest. The CRT was located at eye level, 115 cm from the chinrest.

The premask and search display consisted of outline circles. The outline circles of the premask were red (CIE x, y chromaticity coordinates of 0.629/0.356) and the outline circles of the search display were grey (coordinates of 0.263/0.278); they were matched for luminance (13.5 cd/m^2). The central fixation cross and line segments located within the outline circles of the search display were presented in white (33.0 cd/m^2); the background used for the premask and search display was black (0.3 cd/m^2).

Procedure. The task was similar to that in Theeuwes (1991, 1992), consisting of a visual search task in which there is a clear distinction between the defining and reported attribute of the target. Subjects responded to the orientation (horizontal or vertical) of a line segment appearing in one of the circles of the search display. Because the horizontal or vertical target line segment does not pop-out in a field of slightly tilted non-target line segments, detecting the target line segment required local focused attention (Theeuwes, 1991; Treisman & Gormican, 1988) but not a high spatial acuity. Throughout a trial a fixation cross was presented at the centre of the display. The premask consisted of 15 red outline circles (1.1 deg in diameter) which were presented randomly at any of 30 locations in a 6 × 5 rectangular stimulus array (9.4 × 7.0 deg). Separation of nearest contours between the circles was 0.55 deg in the x-direction, and 0.35 deg in the y-direction. After 3 sec the premask was followed by the search display consisting of 5, 10 or 15 grey outline circles, each containing a line segment (0.5 deg) that was tilted 20 deg to either side of the horizontal or vertical plane. The orientations were randomly distributed in a display. In only one circle, the line segment was oriented either horizontally or vertically; this orientation determined the appropriate response key (the "/"-key for vertical and the "z"-key for horizontal). The 5, 10 or 15 grey circles of the search display were also presented in the same 6 × 5 stimulus array; yet, they were all presented at previously blank locations; i.e. locations which did not contain a circle in the premask. Only in the "target-at-old-location" condition, the search display had one outline circle occupying a location that was not blank in the premask. So, one grey circle was presented at exactly the same location as one of the red circles in the premask. This grey circle presented at a previously occupied location contained

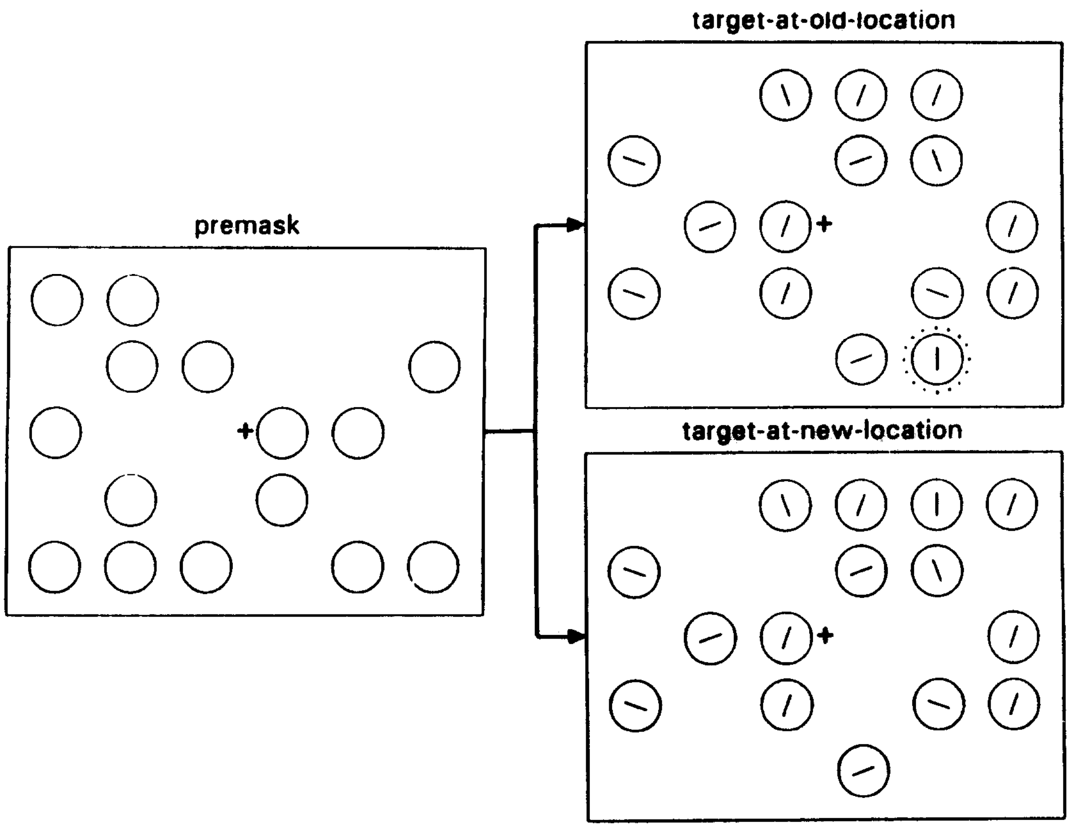

FIGURE 1. Example of display size 15. In the target-at-old-location: 14 circles are presented at new locations, the circle containing the target line segment is presented at an "old" location producing a pop-out (marked by the dots). In the target-at-new-location: all 15 circles are presented at new locations, the circle containing the target line segment is in this example located in the right upper corner, second from the right.

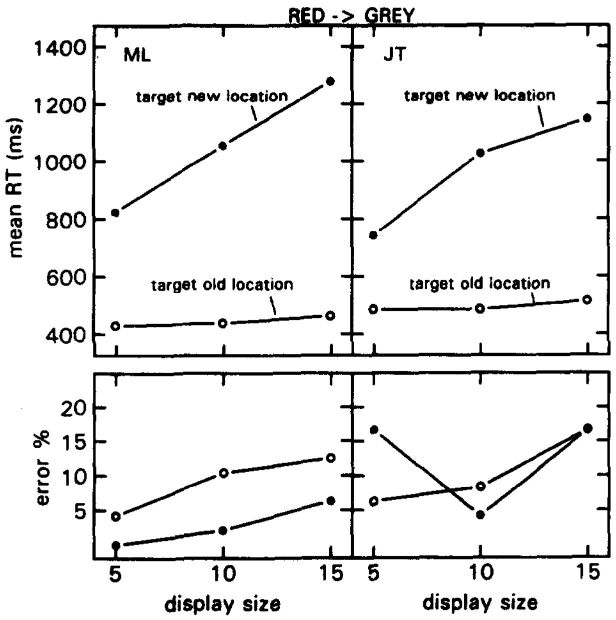

FIGURE 2. Experiment 1: mean reaction time and error percentages for the target-at-old-location and target-at-new-location condition for observer ML and JT with a red premask and a grey search display.

the target line segment determining the appropriate response key. In the "target-at-new-location" condition, the circle containing the target line segment was presented at a previously blank location. Within these constraints, the location of the circle containing the target line segment was randomized from trial to trial. Also, display size (5, 10, 15) was randomized within blocks from trial to trial. The target-at-old-location vs target-at-new-location condition was varied between blocks of trials. The search display remained present for a maximum of 4 sec until a response was emitted. Figure 1 provides examples of the trial events.

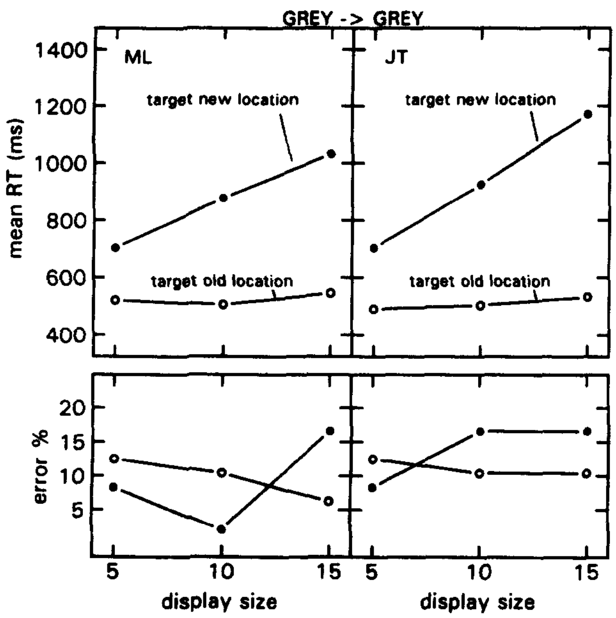

FIGURE 3. Experiment 2: mean reaction time and error percentages for the target-at-old-location and target-at-new-location condition for observer ML and JT with a grey premask and a grey search display.

Both subjects performed 72 practice trials followed by 144 experimental trials in both the "target-at-old-location" and the "target-at-new-location" conditions. A session lasted approx. 50 min, with a 10 min break between the sessions. Within a session, there were short breaks after 36 trials in which subjects received feedback about their performance (percentage errors and mean reaction time) on the preceding block of trials. The subjects knew about the relationship between the location of the target line segment and premask stimulus. Subjects fixated the central cross and were instructed not to move their eyes during the presentation of the premask. Both speed and accuracy were emphasized. A warning beep informed the subject that an error had been committed.

Experiment 2: achromatic pop-out

Experiment 2 was identical to Expt 1, except that *both* premask and search display consisted of grey circles (same CIE values as in Expt 1).

Experiment 3: effect of premask duration

In Expt 3, between blocks of trials, the duration of the premask was varied (1000, 300, 100, 40 msec) for both the chromatic (i.e. premask consisting of red circles) and achromatic (i.e. premask consisting of grey circles) pop-out. Instead of the target-at-new-location condition, the 0 msec premask served as a control condition for both the chromatic and achromatic pop-out.

RESULTS

Experiment 1

Response times longer than 2.5 sec were counted as errors. Search functions (reaction time as a function of number of elements in the display) are given in Fig. 2.

For observer ML, the mean slopes were 3.2 and 45.6 msec/item for target-at-old-location and target-at-new-location condition, respectively. For observer JT, these figures were, respectively, 3.0 and 40.6 msec/item. The flat slope in the target-at-old-location condition (<6 msec/item) indicates that a circle presented at a previously occupied location, pops-out from a field of circles presented at new locations. Phenomenally, it appears that the circle at an old location is slightly bluish-green relative to the grey circles occupying new locations. The serial search functions in the target-at-new-location condition indicate that the pop-out can only be attributed to the fact that the circle was presented at a previously occupied location, and not to peculiarities of the search task or the display configurations.

Experiment 2

Response times longer than 2.5 sec were counted as errors. Search functions are given in Fig. 3.

For observer ML, the mean slopes were 2.4 and 32.7 msec/item for target-at-old-location and target-at-new-location condition, respectively. For observer JT,

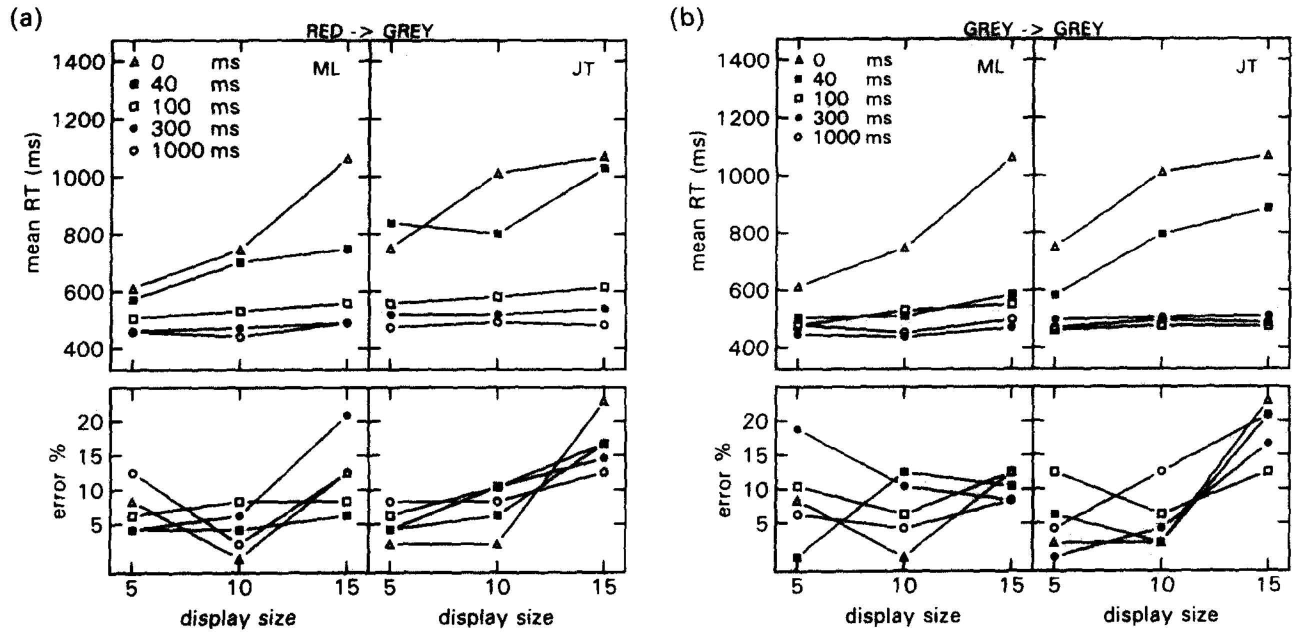

FIGURE 4. (a) Experiment 3: mean reaction time and error percentages for observer ML and JT with a red premask and a grey search display for different premask presentation times. (b) Experiment 3: mean reaction time and error percentages for observer ML and JT with a grey premask and a grey search display for different premask presentation times.

these figures were, respectively, 4.2 and 46.7 msec/item. The slopes of the target-at-old-location condition are similar to those in Expt 1, suggesting an equally strong pop-out for the luminance domain. Phenomenally, the circle at the old location seems to be slightly dimmer than the other circles.

Experiment 3

Response times longer than 2.5 sec were counted as errors. Figure 4(a) gives the search function for the chromatic pop-out and Fig. 4(b) the search function for the achromatic pop-out.

For each search function, shown in Fig. 4(a, b), the slope was calculated. Figure 5(a, b) presents these slopes as a function of premask presentation time. The dotted lines in Fig. 5 indicates a 6 msec/item search slope. Search functions with slopes <6 msec/item are considered to be characteristic of search processes for targets that pop-out. As it is clear from Fig. 5 the pop-out is evident for premask presentation times as short as 100 msec.

The condition with a 40 msec premask presentation time yields search functions that can be thought of as mixtures of complete serial search, as found for the 0 msec control condition (slopes of 30–50 msec/item), and complete parallel search (<6 msec/item) as found for the longer premask presentation times. Such a mixture might possibly occur because only on *some* trials attention is captured by the odd item. Alternatively, because the pop-out is relatively weak, attention might

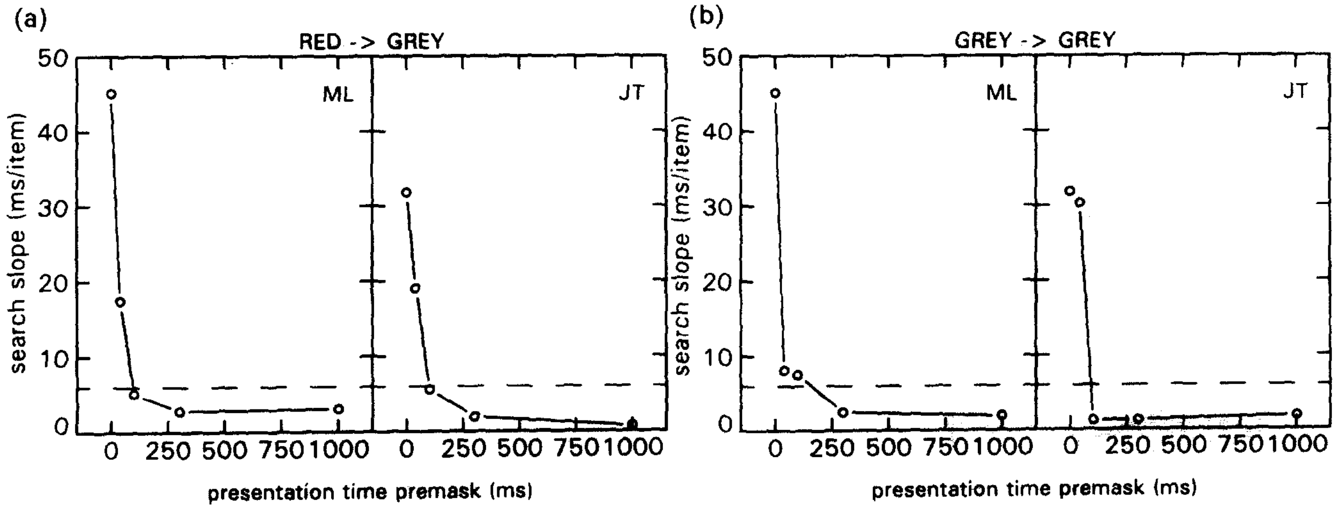

FIGURE 5. (a) Experiment 3: search slope as a function of premask presentation time for observer ML and JT with a red premask and a grey search display for different premask presentation times. (b) Experiment 3: search slopes as a function of premask presentation time for observer ML and JT with a grey premask and a grey search display for different premask presentation times.

be attracted to an approximate area where the odd item is located, requiring still some serial search to exactly locate the target.

DISCUSSION

The experiments were designed to demonstrate that, depending on the stimulus preceding the search display, an object embedded in an array of identical other objects can pop-out. The search slopes of Expt 1 are comparable to those reported by Treisman and Gormican (1988) for detecting colours like magenta, lime and turquoise between their prototypical colour distractor red, green and blue (mean slope reported by Treisman and Gormican: 2.5 msec/item). The search slopes of Expt 2 are comparable to those reported by Theeuwes (1991) for detecting a brighter or dimmer object between other equiluminant objects [mean slope reported by Theeuwes (1991): 2.7 msec/item]. These comparisons indicate that the present adaptation-induced pop-out is as strong as the pop-out found in a search display in which there is a physical difference in colour or luminance. The results of Exp 3 are rather surprising, because it was not expected that a reliable pop-out effect would occur with premasks presentation times as short as 100 msec.

Phenomenally, the chromatic pop-out appears to be stronger than the achromatic pop-out: one circle is clearly bluish-green while the others are grey; yet, the data indicate that the achromatic pop-out yield equally strong effects. The pop-out can be completely explained by physiological processes at the level of the retina. The visual effect that can be generated by these processes is usually referred to as *local* (*chromatic*) *adaptation*,* *successive contrast*, or (*colour*) *afterimage* (e.g. Boynton, 1979; Brown, 1965; Cornsweet, 1970). It also has been demonstrated that the effect is not confined to colour, but is also present in the achromatic domain (Hurvich & Jameson, 1966).

Any visual stimulus has an effect on the local adaptation state of the receptors in the portion of the visual field that is exposed to that stimulus. When the stimulus is red, as the premasks in Expts 1 and 3, at each location the red cones are stimulated most and will adjust their sensitivity so as to more or less re-balance the outputs of the red, green and blue cones (chromatic adaptation). At that moment, the particular retinal area has become less sensitive to red light and, therefore, more sensitive to the light of the colour that is approximately complementary to red (i.e. bluish-green in this case). When this red-desensitized retinal area is stimulated with a grey colour which normally stimulates the red, green and blue cones about equally, the colour signals generated by the blue and green cones will exceed that of the red cones, resulting in the perception of a bluish-green colour. The adaptation process, as described here for red and grey, can be applied to any colour combination including luminance. The results of Expt 3 indicate that the local adaptation processes involved are fast.

The important finding of the present study is that an apparently irrelevant display presented as short as 100 msec before a target display can change the search function completely from serial to parallel. Because one object is presented at a previously occupied location, it pops-out due to the effect of local adaptation. In the present study, the popping-out object was the target, so as to demonstrate the associated pop-out. Yet, given the same circumstances, the adaptation-induced pop-outs might occur in *any* visual search task for both targets and non-targets. In studies in which no eye-movements are allowed (e.g. most of the studies on attention), the adaptation-induced pop-out might occur especially because pop-outs operate automatically and unintentionally (Treisman, 1988). In this type of study, the subtle occurrence of an adaptation-induced pop-out effect might contaminate the data. Note, however, that also in search tasks in which the eyes are not fixed, an afterimage may induce a pop-out when the contours of an element in the search display fit the contours of the premasking stimulus.

*To ensure that the present findings are due to adaptation or successive contrast rather than to the detection of the only location that is occupied twice, an additional condition was run in which a 100 msec blank interval was presented between the premask (a 300 msec red premask) and the search display. Similar pop-out effects were found in this condition (mean slopes of 0.6 and −0.2 msec/item for observer ML and JT, respectively), indicating that the alternative explanation does not hold. In addition, presenting the premask display to one eye and the search display to the other eye gave no pop-effect, indicating that the pop-out is most likely due to retinal adaptation rather than adaptation at some higher level.

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