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A SPURIOUS POP-OUT IN VISUAL SEARCH

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SUMMARY

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 color (Experiment 1) or brightness (Experiment 2) that is slightly different from the color 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 100 ms. The present findings have severe implications on the design of experiments in which no eye movements are allowed involving multiple displays presented in successive order.

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Een nieuwe "pop-out" in visueel zoeken

J. Theeuwes en M.P. Lucassen

SAMENVATTING

In deze studie wordt aangetoond dat een object geplaatst tussen identieke andere objecten eruit kan springen ("pop-out"). De premasking stimulus die voorafgaat aan het display veroorzaakt een lokale chromatische adaptatie waardoor één van de objecten een kleur (Experiment 1) of helderheid (Experiment 2) lijkt te hebben die afwijkt van de kleur en helderheid van de andere objecten in het visuele veld. Experiment 3 laat zien dat deze pop-out zelfs optreedt wanneer de premasking stimulus slechts gedurende 100 ms wordt aangeboden. De bevindingen hebben implicaties voor het ontwerp van experimenten waarin verschillende displays snel achter elkaar worden aangeboden.

1 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 (less than 5 or 6 ms 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 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, color, brightness, shape, etc. (see Enns, 1990, for a review).

The present study demonstrates a new pop-out phenomenon based on 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 color (chromatic pop-out; Experiment 1) or brightness (achromatic pop-out; Experiment 2) which is slightly different from the color 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 adapted to the color and brightness of the preceding masking stimulus. Experiment 3 investigates the time course of the spurious chromatic and achromatic pop-out effect; how long the adaptation time must be in order to obtain the pop-out effect.

2 METHOD

Experiment 1

Subjects. Two experienced observers (the authors) participated in all experiments. Both had corrected-to-normal acuity and reported having no color defects.

Apparatus and Stimuli. A SX-386 Personal Computer (G2) with a NEC Multisync 3D VGA color screen (resolution 640x350) controlled the timing of the events, generated pictures and recorded reaction times. 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 outline circles of the premask were red (CIE x,y chromaticity coordinates of .629/.356) and the outline circles of the search display were grey (coordinates of .263/.278) and were matched for luminance (13.5 cd/m²). The fixation cross and the line segments were presented in white (33.0 cd/m²); the background used for the premask and search display was black (0.3 cd/m²).

Procedure. The task was similar to that in Theeuwes (1991, 1992), consisting of a visual search task in which there is a clear separation 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 subjects responded to the orientation of a target line segment located among slightly tilted nontarget line segments, the task required focal attention (Theeuwes, 1991; Treisman & Gormican, 1988) but not a high spatial acuity. Throughout a trial a fixation cross was presented at the center of the display. The premask consisted of 15 red outline circles (1.1° of diameter) which were presented randomly at any of 30 locations in a 6 by 5 rectangular stimulus array (9.4° x 7.0°). Separation of nearest contours between the circles was .55° in the X-direction, and .35° in the Y-direction. After 3 s the premask was followed by the search display consisting of 5, 10 or 15 grey outline circles, each containing a line segment (.5°) which was tilted 20° 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 x 5 stimulus array; yet, they were all presented at previously blank locations; that is, 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 which was not blank in the premask; one grey circle was presented at exactly the same location as one of the red circles in the premasks. This grey circle presented at a previously occupied location contained 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 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 from trial to trial. The search display remained present for a maximum of 4 s until a response was emitted. Fig. 1 provides examples of the trial events.

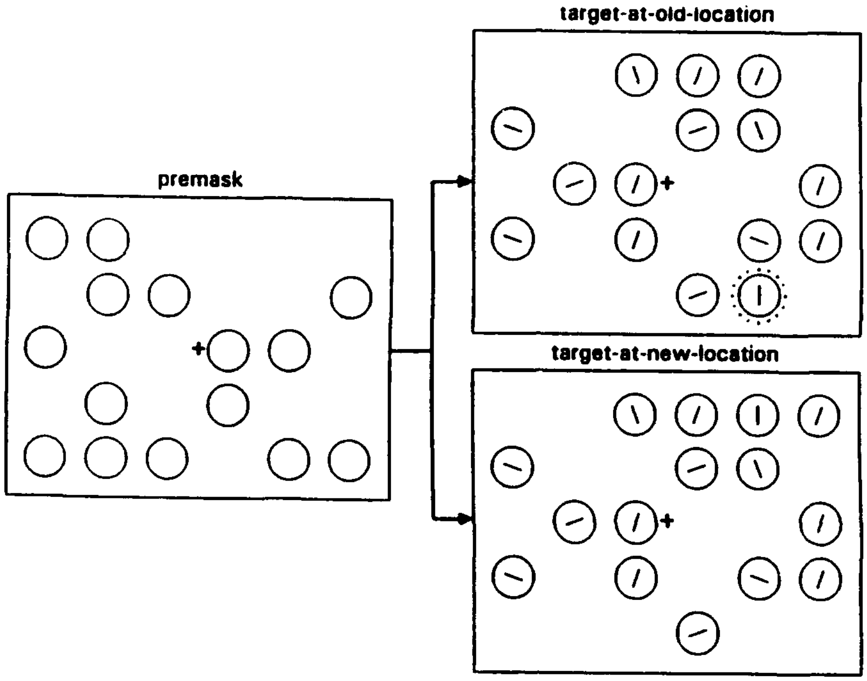

Fig. 1 Example of Display Size 15. In the target-at-old-location: 14 circles are presented at new locations, the circle containing the target line segment is presented at an old location producing a pop-out (marked by the dots). In the target-at-new-location: all 15 circles are presented at new locations,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

Both subjects performed 72 practice trials followed by 144 experimental trials in both conditions. A session lasted approximately 50 minutes, with a 10 minute 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 did not 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

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

Experiment 3

In Experiment 3 the duration of the premask was varied (1000, 300, 100, 40 ms) 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 ms premask served as a control condition for both the chromatic and achromatic pop-out.

3 RESULTS

Experiment 1

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

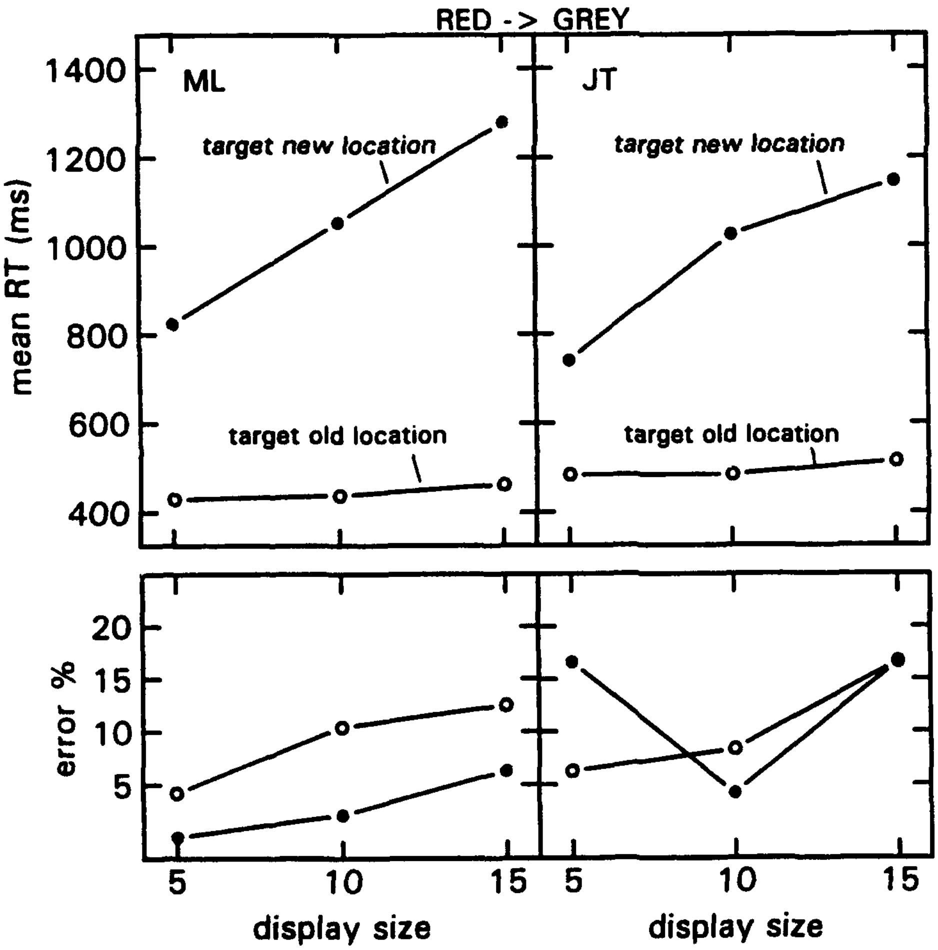

Fig. 2 Experiment 1: Mean reaction time and error percentages for the target-at-old-location and target-at-new-location condition for observer ML and JT with a red premask and a grey search display.

For observer ML, the mean slopes were 3.2 and 45.6 ms/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 ms/item. The flat slope in the target-at-old-location condition (less than 6 ms/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 s were counted as errors. Search functions are given in Fig. 3.

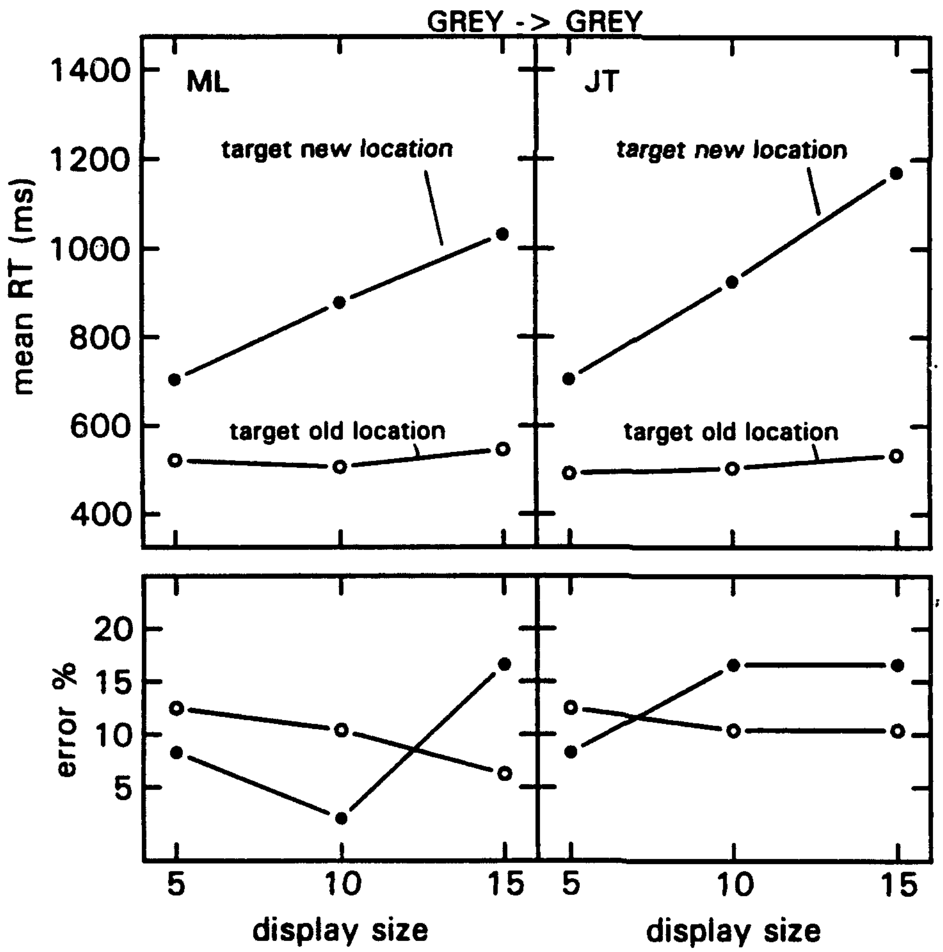

Fig. 3 Experiment 2: Mean reaction time and error percentages for the target-at-old-location and target-at-new-location condition for observer ML and JT with a grey premask and a grey search display.

For observer ML, the mean slopes were 2.4 and 32.7 ms/item for target-at-old location and target-at-new-location condition, respectively. For observer JT, these figures were, respectively, 4.2 and 46.7 ms/item. The slopes of the target-at-old-location condition are similar to those in Experiment 1, suggesting an equally strong pop-out for the luminance domain. Phenomenally, the circle at an old location seems to be slightly dimmer than the other circles.

Experiment 3

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

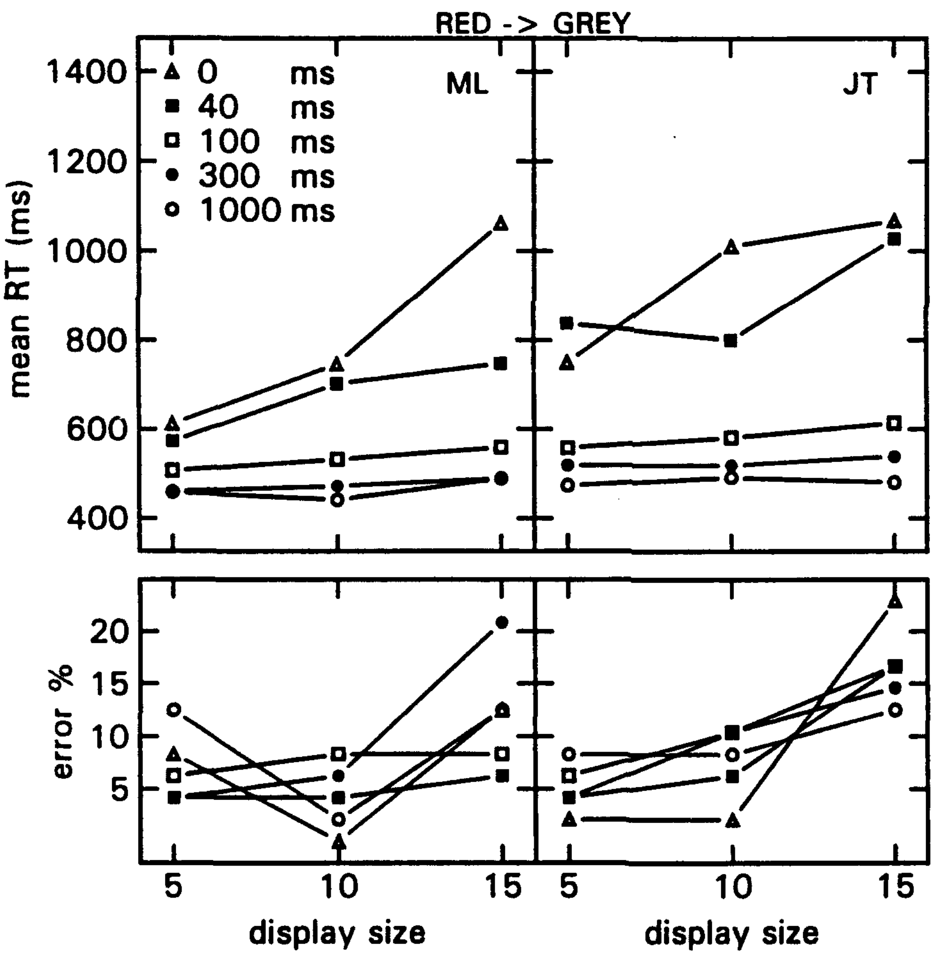

Fig. 4a Experiment 3: Mean reaction time and error percentages for observer ML and JT with a red premask and a grey search display for different premask presentation times.

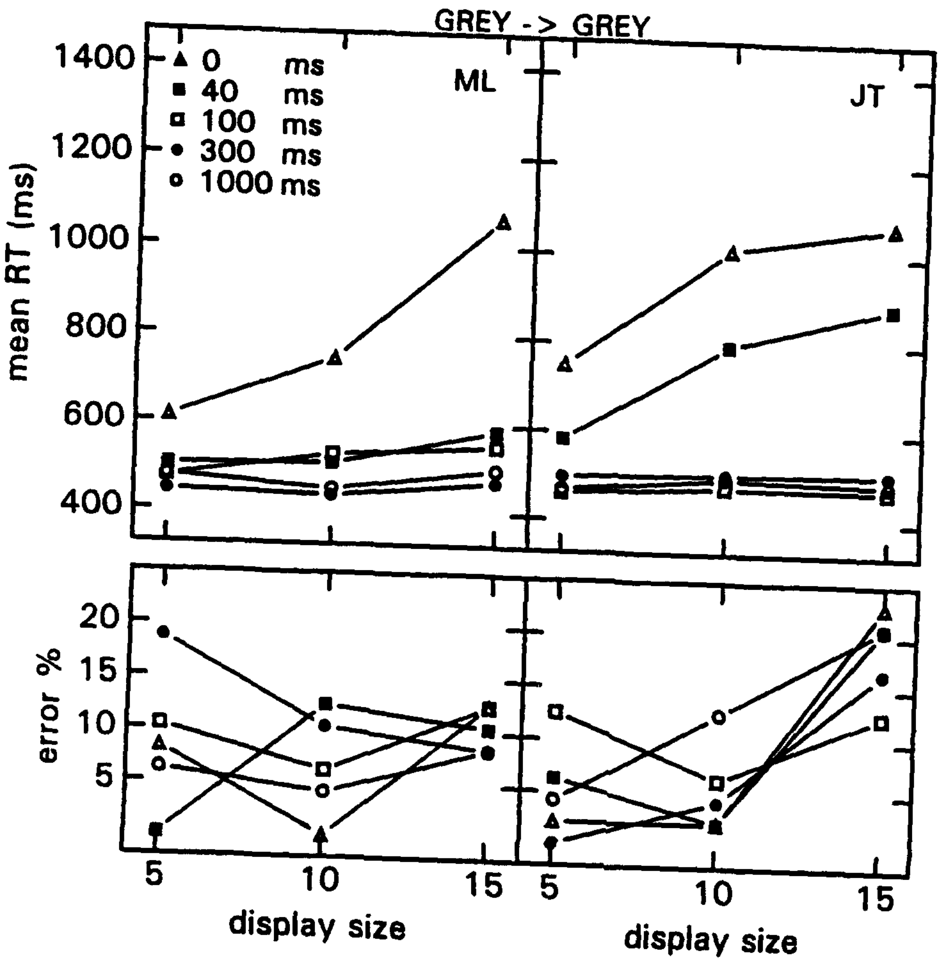

Fig. 4b Experiment 3: Mean reaction time and error percentages for observer ML and JT with a grey premask and a grey search display for different premask presentation times.

For each search function, the slope was calculated. Figs 5a and 5b give these slopes as a function premask presentation time. The dotted line indicates 6 ms/item search slope; search functions having slopes which are less than the 6 ms/item are considered to represent search processes in which the target pops-out. As is clear from Fig. 5 the spurious pop-out is evident for presentation times as short as 100 ms.

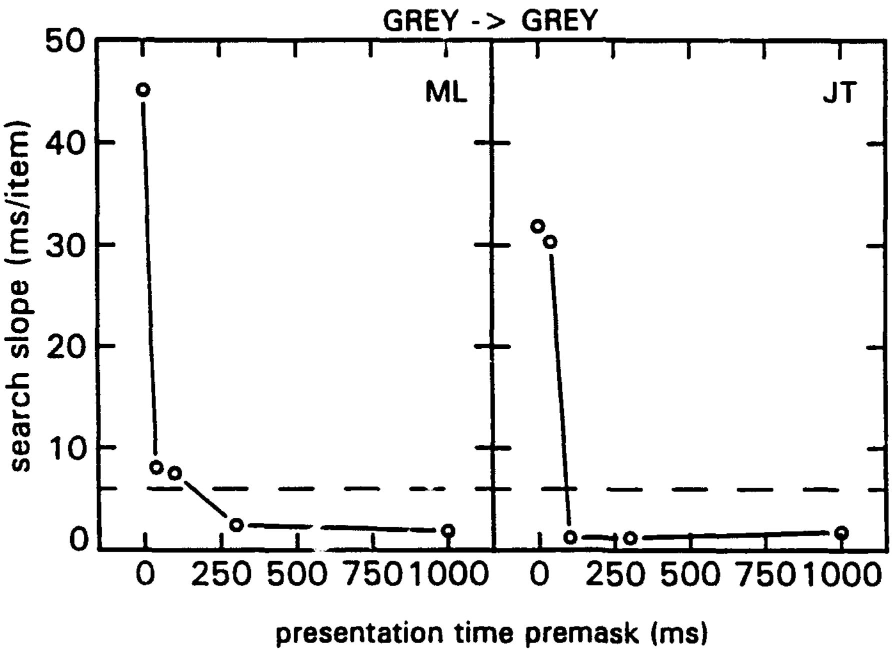

Fig. 5a Experiment 3: Search slope as a function of premask presentation time for observer ML and JT with a red premask and a grey search display for different premask presentation times.

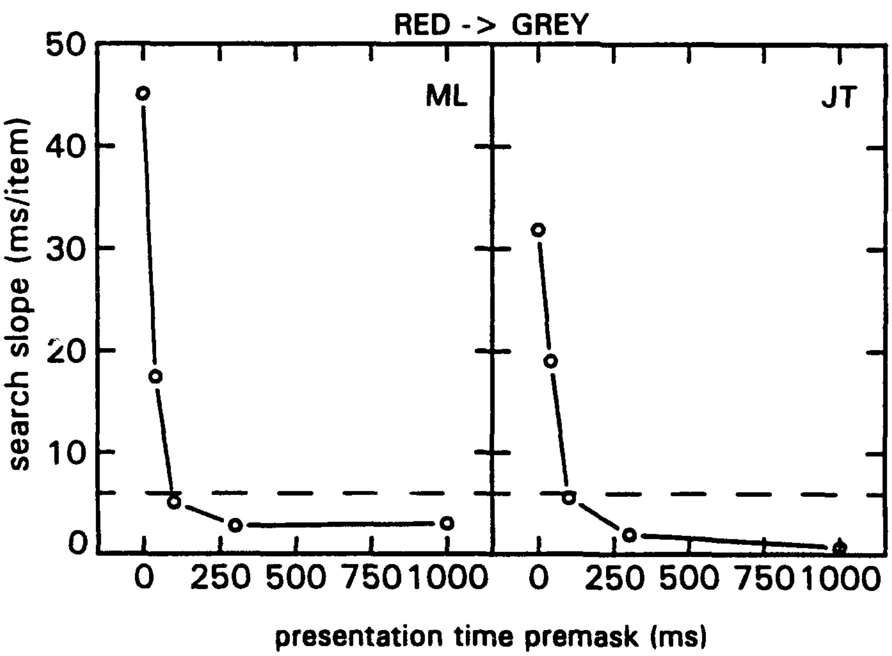

Fig. 5b Experiment 3: Searc.ı slopes as a function of premask presentation time for observer ML and JT with a grey premask and a grey search display for different premask presentation times.

The 40 ms presentation time gives search functions which are mixtures between complete serial search as found for the 0 ms control condition (search functions between 30 and 50 ms/item) and complete parallel search (less than 6 ms/item) as found for the longer premask presentation times. Such a mixture might occur because only on some trials attention is captured by the odd item. Alternatively, because the pop-out is relatively weak, attention might be attracted to an approximate area where the odd item is located, requiring some serial search to locate the target precisely.

4 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 Experiment 1 are comparable to those reported by Treisman and Gormican (1988) for detecting colors like magenta, lime and turquoise between their prototypical color distractor red, green and blue (mean slope reported by Treisman & Gormican: 2.5 ms/item). The search slopes of Experiment 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: 2.7 ms/item). These comparisons indicate that the present spurious pop-out is as strong as the pop-out's found in a search display in which there is a physical difference in color or luminance. The results of Experiment 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 ms.

Phenomenally, the chromatic pop-out appears to be much stronger than the achromatic pop-out: one circle is clearly bluish-green while the other are grey; yet, the data indicate that the achromatic pop-out gives comparable effects. The reason that the object pops-out is purely physiological and is usually referred to as *local (chromatic) adaptation*, *successive contrast*, or *(color) afterimage* (e.g., Boynton, 1979; Brown, 1965; Cornsweet, 1970). It also has been demonstrated that the effect is not confined to color, 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 Experiment 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 and, therefore, more sensitive to the color that is approximately complementary to red (i.e., bluish-green for the chromatic pop-out). When this red-desensitized retinal area is stimulated with a grey color which normally stimulates the red, green and blue cones about equally, the color signals from the blue and green cones will exceed that of the red cones, resulting in the perception of a bluish-green color. The adaptation process demonstrated for red and grey can be applied to any color combination including luminance. Experiment 3 indicates that the local adaptation processes involved are fast.

The important finding of the present study is that an irrelevant display presented as short as 100 ms before a target display can change the search function completely from serial to parallel. Because one object is presented at previously occupied location, it pops-out. 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 spurious pop-out's 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 spurious pop-out might occur especially because pop-out's operate automatically and unintentionally (Treisman, 1988). It should be noted that with short premask presentation times, phenomenally, the pop-out is not vivid. The only thing that is noted is that the target is found very fast.

In the literature on visual search, several paradigms make use of displays presented in a successive order (e.g., multiple-frame attention tasks) without considering the possible occurrence of spurious pop-out's. Especially in experiments in which the manipulation of an independent variable is systematically related to the occurrence of a spurious pop-out, the spurious pop-out might contaminate the data. *It should be noted* that the occurrence of spurious pop-out's is not limited from one display to the next, but can extend over multiple displays as long as no eye movements are made.

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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 color (Experiment 1) or brightness (Experiment 2) that is slightly different from the color 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 100 ms. The present findings have severe implications on the design of experiments in which no eye movements are allowed involving multiple displays presented in successive order.

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