Fluorescent Colored Stimuli Automatically Attract Visual Attention: An Eye Movement Study

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Fluorescent colored materials possess qualities that can lead to enhanced visibility and safety. However, little is known about the mechanisms that mediate this enhanced visual conspicuity. Previous studies using visual search paradigms suggest that the enhanced conspicuity of fluorescent colors stems from top-down attentional mechanisms; and, offer no support for the claim that fluorescent colored stimuli can automatically attract visual attention in a strictly bottom-up fashion. As an alternative to visual search techniques, the present study investigated eye movement behavior to ascertain whether an unexpected presentation of a fluorescent colored stimulus would be likely to capture initial visual fixations to the onset of a multi-stimulus array. Results of the study indicate that, compared to non-fluorescent colored stimuli, the fluorescent colored target was much more likely to elicit initial fixations. Contrary to previous studies, these findings support the claim that fluorescent colors can automatically attract visual attention via bottom-up mechanisms.

Introduction

Recent research, especially within the domain of traffic engineering and safety, has demonstrated the improved visual performance afforded by the use of fluorescent colored materials relative to their non-fluorescent colored equivalents. Fluorescent colored highway signs can be detected at significantly greater distances (Burns & Pavelka, 1995; Jenssen, et al., 1996) and yield better vehicular slowing and lane change behavior upon approaching roadway hazards (Eccles & Hummer, 2001). Evidence has also accrued that the use of fluorescent colored markings improves the conspicuity of emergency vehicles in traffic (Solomon & King, 1997).

Despite the growing evidence of the efficacy of fluorescent colored materials for traffic safety very little work has been done to determine the behavioral mechanisms that mediate their visual performance advantages. Schieber, et al. (2001) used a novel visual search paradigm in an attempt to determine whether the improved visual conspicuity of fluorescent colored highway signs was mediated by bottom-up or top-down attentional mechanisms. They found that visual search was markedly more efficient for a target symbol that appeared on a fluorescent colored sign compared to non-fluorescent colored controls. However, this improvement occurred only when the observers had prior knowledge about the fact that the target location was related to color appearance. No visual search advantage was observed when the search target appeared on a novel, unexpected fluorescent colored sign (using an inattention search paradigm; see Mack & Rock, 1998). These results have subsequently been replicated for a range of fluorescent colored materials commonly used in highway signs and other safety applications (Schieber, 2002). The authors of these studies have interpreted these findings to indicate that fluorescent colored materials yield superior visual performance because of top-down guidance of attention rather than via bottom-up mechanisms thought to automatically attract the focus of attention. This distinction, although subtle, has profound implications for the manner in which fluorescent colored materials should be deployed in the service of improved visual conspicuity and safety.

The failure to observe a bottom-up attentional conspicuity effect for fluorescent colored materials was not anticipated. Previous field studies had yielded results which strongly favored the interpretation that fluorescent colored highway signs automatically recruited drivers' focal attention (e.g., Jenssen, et al., 1996; Eccles & Hummer, 2001). However, retrospective examination of the inattention search paradigm used by Schieber, et al (2001; 2002) suggests an alternative explanation for their findings. Their experimental procedure required participants to search for an up-arrow target embedded upon one of four signs that varied in color. No fluorescent colored stimuli appeared during this phase and there was no predictive or otherwise systematic relationship between sign color and target location. On the critical 33rd stimulus trial, a fluorescent colored singleton (containing the up-arrow target) was introduced for the first time. If fluorescent colors automatically attracted attention in a bottom-up fashion, then one would expect a reduction in search time on trial 33 relative to the previous trials. Failure to observe the anticipated improvement in performance on this critical trial lead to the conclusion that fluorescent colored materials do not "grab" one's attention in an automatic, bottom-up manner.

It is possible, however, that the observers in these experiments learned to actively suppress color information during the initial 32 trials of this experimental paradigm since color was unrelated to target location and served only as a distractor in these cases. If such active suppression of the distracting influences of color information did occur then one might expect that any bottom-up attentional attraction to the initial occurrence of the fluorescent colored singleton on trial 33 may have been muted.

Given the possibility that observers in the aforementioned studies (1) may have developed an active suppression of color information, and (2) that this active suppression of color information may have masked potential bottom-up attention effects upon the unexpected appearance of the fluorescent colored sign; an alternative experimental approach was developed to re-evaluate the proposition that fluorescent colored materials may automatically attract attention in a bottom-up fashion. This new approach used eye tracking technology to determine whether a fluorescent colored stimulus would be more likely to attract initial fixation upon presentation than its non-fluorescent colored counterparts. The experimental protocol was designed to be as simple as possible to avoid the likelihood of systematically introducing top-down influences that might serve to mask bottom-up attentional attraction to the targets. If fluorescent colors do not automatically attract attention in a bottom-up fashion then the unexpected appearance of a highly salient fluorescent colored target should be no more likely to capture initial eye fixations than its non-fluorescent stimulus counterparts. However, if such bottom-up effects do exist (but were masked by the development of active color suppression in the previous studies) then one would predict the unexpected appearance of a fluorescent colored stimulus to capture the initial eye gaze fixation upon display onset.

Method

Participants. A total of 24 individuals recruited from undergraduate psychology classes at the University of South Dakota participated in this study. All observers had normal acuity and color vision (AO pseudoisochromatic plates).

Apparatus and materials. Six different stimuli were used. Five consisted of 4x4 inch metallic plates covered with sheeting material of a given color: red, yellow, orange, green or fluorescent yellow-green. A sixth 4x4 inch plate contained a circular cluster of 16 hexagonally-packed red and yellow light-emitting diodes (LEDs) that flashed on-and-off at a rate of 4 Hz (0.3 degrees; 1500 cd/m^2). A flashing light is a well established stimulus for automatically attracting attention (and eye fixations) in a bottom-up manner. Hence the flashing LED stimulus served as a *ground truth* reference by which to judge the attention-getting properties of the experimental fluorescent colored target. On any given trial, four of the stimuli were mounted at 4 of 8 possible positions (see Figure 1) according to a predetermined random order. These stimuli were mounted behind a 1x1 meter sheet of electrochromic glass (viewed at a distance of 20 ft to control for accommodative load) that acted like a computer-activated shutter to control the onset and exposure times of each stimulus trial. The electrochromic glass was opaque in its off-state but immediately (< 50 msec) transitioned to its “clear” state upon being activated. The stimuli were illuminated with broad spectrum lights to insure realistic daylight color rendering and the activation of the fluorescing pigments in the fluorescent yellow-green stimulus (see Figure 2).

Procedure. After completing the informed consent and visual screening procedure, each participant was fitted with the head-mounted eye tracker (ASL Model 501; 60 Hz). The participants were required to fixate a small black cross in the center of the electrochromic display window before each trial could begin. Each trial consisted of a 5 second exposure of the 4 targets mounted behind the electrochromic window. Participants were instructed to inspect each stimulus array (in anticipation of follow-up inquiries by the investigators at the end of the experiment). Eye movement data were recorded during each trial. Sixteen *control trials* each consisting of the four non-fluorescent stimuli were presented in predetermined random orders. Trials 9 and 18 represented the *experimental trials* in which the yellow sign was unexpectedly replaced with either the fluorescent yellow-green target or the flashing LED target. The relative order of the experimental stimuli was counterbalanced across subjects. Each stimulus, control and experimental, occurred an equal number of times at each potential stimulus location across the experiment.

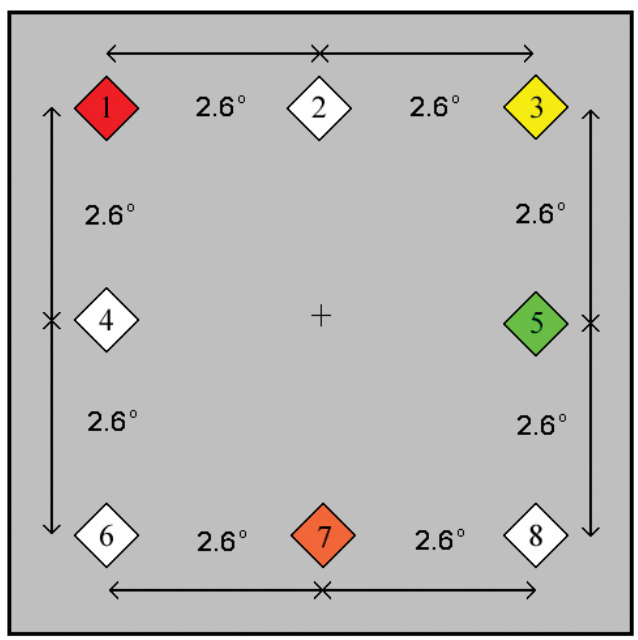
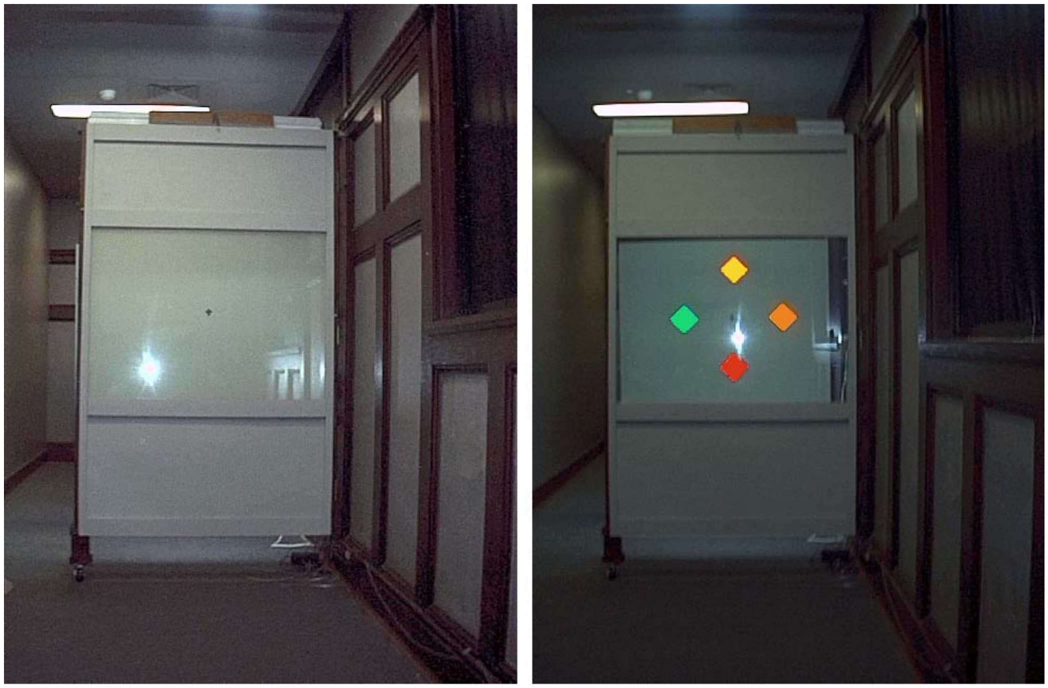


Figure 1. Eight possible stimulus positions around central fixation point. Shaded locations represent placements for a typical 4-stimulus trial.



A. Window Closed B. Window Open

Figure 2. Electrochromic window in closed state (A) and opened state (B). Note the centrally located fixation point used at the start of each eye tracking trial.

Results

An off-line analysis of the eye movement records was performed to reconstruct the time series depicting eye gaze behavior on each trial. For each stimulus trial the following information was determined: (1) the order of the first eye gaze fixation for each stimulus presented, (2) the total glance time per stimulus and (3) the total number of fixations elicited by each stimulus.

The data analysis most closely related to the question regarding the ability of the experimental stimuli to elicit bottom-up attentional attraction involved the <u>average order of the first fixation</u> to each stimulus category (i.e., fixation priority). The average fixation priority scores for the six stimulus categories are presented in Table 1. Examination of this table reveals that, on average, the first fixation to a non-fluorescent colored control stimulus did not occur until approximately the 3rd glance within the stimulus array. ANOVA results indicated that none of the non-fluorescent colored control stimuli differed from one another [**F**(3,69) = 1.25, p > 0.1]. However, both of the experimental stimuli were very likely to have attracted the 1st or 2nd glance within the stimulus array. Compared to the non-fluorescent controls, the average order of the first glance was significantly *higher in priority* (i.e., sequentially more early) for both the fluorescent yellow-green [**F**(1,23) = 66.9, p < 0.001] and LED stimuli [**F**(1,23) = 23.8, p < 0.001]. Glance priority did not significantly differ across the experimental stimuli [**F**(1,23) = 0.1, p > 0.1].

Table1.
Mean Order of First Glance (i.e., Fixation Priority) by Stimulus Category

Control Stimuli				Experimental Stimuli	
Red	Green	Yellow	Orange	Fluorescent Yellow-Green	LEDs
2.87	2.76	2.63	2.82	1.46	1.54

Total glance time and number of fixations per stimulus category represent the combined influences of both top-down and bottom-up attention mechanisms. ANOVAs performed upon the *total glance time* data (see Table 2) revealed that none of the control stimuli differed from one another [**F**(3,69) = 1.13, p > 0.1]. Both the fluorescent colored stimulus [**F**(1,23 = 57.6, p < 0.001] and the flashing LED [**F**(1,23) = 38.2, p < 0.001] attracted more total glance time than the non-fluorescent controls.

Total time spent looking at the flashing LED target was significantly longer than for the fluorescent colored stimulus [$\mathbf{F}(1,23) = 5.46$, $p < 0.05$]. A similar pattern of results was obtained for the analysis of the *number of fixations* elicited across stimulus categories (see Table 3).

Table 2.
Mean Total Glance Time (msec) by Stimulus Category

Control Stimuli				Experimental Stimuli	
Red	**Green**	**Yellow**	**Orange**	**Fluorescent Yellow-Green**	**LEDs**
886	888	947	888	1868	2297

Table 3.
Mean No. of Fixations per Trial by Stimulus Category

Control Stimuli				Experimental Stimuli	
Red	**Green**	**Yellow**	**Orange**	**Fluorescent Yellow-Green**	**LEDs**
1.82	1.92	1.85	1.89	3.12	2.12

Discussion

Contrary to the findings of several previous studies in our laboratory using a novel visual search paradigm, the results of the current investigation indicate that a fluorescent colored stimulus can automatically attract attention in a purely bottom-up fashion. The fluorescent yellow-green stimulus was presented unexpectedly on only a single trial (either trial 9 or 18). Hence, it was completely independent of any attentional contingencies based upon *a priori* (or, top-down) expectancies. The fact that the fluorescent colored target elicited the very first fixation from 16 of 24 observers is strong evidence for stimulus-driven (bottom-up) attentional guidance (Note: The remaining 8 observers glanced at the fluorescent target on their 2nd fixational eye movements).

It is unfortunate that the design of the current investigation did not include an unexpected non-fluorescent colored stimulus (e.g., a "white" sign) which may have enabled us to distinguish the effects of stimulus "novelty" from the effects of stimulus fluorescence, *per se*. Such a stimulus condition was not included since our previous findings led us to hypothesis that only the *ground truth* flashing LED stimulus (but not the fluorescent yellow-green stimulus) would attract priority eye fixations. However, despite this shortcoming in the experimental design, the results of the current study conclusively warrant a re-evaluation of our previous claim that "fluorescent colored signs don't 'grab' attention; they 'guide' it" (Schieber, et al., 2001).

References

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