Searching for Fluorescent Colored Highway Signs: Bottom-Up versus Top-Down Mechanisms

Frank Schieber
Heimstra Human Factors Laboratories
University of South Dakota
Vermillion, SD 57069

schieber@usd.edu
http://www.usd.edu/~schieber

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Abstract

A novel *inattention search paradigm* (Mack & Rock, 1998) was used to assess the visual efficiency of fluorescent colored relative to nonfluorescent colored highway signs in a laboratory setting. Unexpected presentation of a fluorescent colored search target was not accompanied by an improvement in visual search time. However, visual search times improved dramatically once the participants developed the expectancy that the target feature would be presented on a fluorescent colored *singleton*. This pattern of results suggests that many of the visibility advantages attributed to the use of fluorescent colors in safety applications may be mediated by *top-down* attentional mechanisms rather than *bottom-up* (preattentive) mechanisms as previously assumed.

Introduction

Fluorescent colored materials are now being widely used for the construction of highway signs and hazard/warning markers. It is commonly assumed that because fluorescent materials are brighter and more colorful that they will be more *conspicuous* than their non-fluorescent counterparts. In fact, there is significant evidence that fluorescent traffic signs can be detected at greater distances (Burns & Pavelka, 1995), recognized and understood sooner (Jennsen, et al., 1996) and more reliably impact traffic control operations (Hummer & Scheffler, 1999). Yet, little is known about the visual mechanisms that mediate the superior performance levels afforded by the use of fluorescent colored materials in highway sign construction.

One of the assumptions that pervades the literature on the visibility of fluorescent colored materials used in safety research is that fluorescent colors "grab your attention". Stated more precisely: Fluorescent signs are presumed to "popout" from their non-fluorescent colored backgrounds in a manner that supports effortless, fast/parallel search processes. Furthermore, there seems to be a pervasive assumption that the reason fluorescent colored signs popout is because they can involuntarily "recruit" the focus of attention via *preattentive* or *bottom-up* visual mechanism(s). To date, however, neither of these assumptions has been directly tested.

Mack and Rock (1998) have demonstrated that traditional visual search methods used to study preattentive (i.e., bottom-up) perceptual processes do not necessarily eliminate the possible contribution (i.e., confound) of *top-down* attentionally guided processes. In response to this criticism, they have developed and validated the *inattention paradigm*: a new group of techniques better suited to separating preattentive/bottom-up processes from top-down attentional mechanisms during visual search. The current investigation uses a variant of the inattention paradigm to ascertain whether or not fluorescent colored materials can facilitate visual search through a set of multicolored signs by preattentively "grabbing" attention in true bottom-up fashion.

Experiment 1

Experimental Condition: Unexpected Fluorescent Yellow-Green Target.

Participants. Forty-two students (ages 18-30 years) recruited from undergraduate classes at the University of South Dakota served as unpaid volunteer participants.

Apparatus and Materials. A series of 5x5 inch sheet metal signs were prepared to serve as stimuli in a visual search protocol. Each sign was covered with retroreflective sheeting material from one of five standard highway sign colors: *red, green, yellow, orange and fluorescent yellow-green*. A bold black *arrow* symbol was then affixed to the center of each sign. The signs were mounted on a vertical matte gray surface via prepositioned magnets. These stimuli were illuminated by several banks of broad spectrum fluorescent lamps (6500 °K). These lamps provided illumination with color rendering capacity "simulating" noontime sunlight based upon evaluation of the stimuli and the illuminant using a Photo Research PR-650 spectroradiometer. The illumination chamber and the stimuli mounted therein were separated from observer via a 1x1 meter pane of electrochromic glass that served as a computer-controlled "electronic shutter" to allow careful and accurate control of stimulus "onset" time. That is, the electrochromic glass could be programmed to change "instantaneously" from an opaque state (blocking the participant's view to the stimuli) to a transparent state (allowing wide angle, unobstructed visual access to the stimuli in the illumination chamber). The sign stimuli were mounted in a vertical plane 6 ft posterior to the electrochromic viewing window while the observer was position at a table 20 ft anterior to the viewing window. A small centrally located fixation cross was mounted on the anterior surface of the viewing window so that it was always visible. The electrochromic window and the stimuli were both at a viewing distance equivalent to *optical infinity*. Hence, little or no change in ocular accommodation was required when the viewing window transitioned from the opaque to transparent state. A console with 4 push-buttons at the 12, 3, 6 and 9 o'clock positions (top, right, bottom and left, respectively) was used to collect participant responses.

Table 1. Stimulus Photometric Properties.

	CIE 1931		
Background	Luminance	Chromaticity	
Color	(cd/m^2)	x	y
Red	6.92	0.471	0.305
Green	6.66	0.206	0.361
Yellow	18.88	0.442	0.438
Orange	12.48	0.492	0.363
Fluorescent Yellow-Green	53.89	0.385	0.544

Procedure. The inattention search paradigm was implemented as follows: Each experimental trial began with the abrupt presentation of four stimulus signs in the spatial configuration depicted in **Figure 1**. The participant was required to search quickly through the stimulus array in order to locate the position of the stimulus with an arrow

pointed in the "up" direction. Upon finding the up-arrow target, the participant was required to manually enter a response via a push-button console that was interfaced to the computer controlling the timing of the experimental protocol.

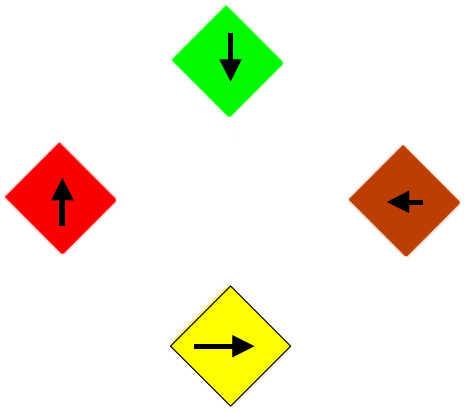

Figure 1. Spatial configuration of search paradigm stimuli.

On every trial, all four cardinal positions for the arrow (up, down, left, right) were represented. During the initial 32 trials, the position of the four non-fluorescent colored stimuli (red, green, yellow, orange) as well as the orientation of the four arrow directions were completely randomized. However, beginning on the 33rd stimulus trial the presentation rules changed (without forewarning the experimental participant). For trials 33-48 the yellow sign was replaced with the fluorescent yellow-green stimulus. Furthermore, the up-arrow target ALWAYS appeared on the fluorescent yellow-green sign during these last 16 experimental trials. Otherwise, the positions of the sign colors and arrow direction were randomized as on trials 1-32. As will be discussed below, *performance on trial 33 is of particular interest since this is the only trial where the fluorescent colored stimulus had the opportunity to "deflect" attention without the potential of being influenced by systematic top-down processes*.

Prior to the start of the experimental trials, participants completed the informed consent procedure (as approved by the USD Committee for the Protection of Human Subjects). Participants also completed a minimum of 8 practice trials prior to the start of the experiment.

Yellow Stimulus Control Condition

Participants. Thirty students (ages 18-30 years) recruited from undergraduate classes at the University of South Dakota served as unpaid volunteer participants. None of these subjects served as participants in the fluorescent yellow-green experimental condition described above.

Procedure. The non-fluorescent yellow control condition was identical in all ways to the experiment described above except that the fluorescent yellow-green stimulus did **not** replace the yellow sign on trials 33-48. Hence, the participants in this control condition never saw the fluorescent colored sign. Instead, the up-arrow target always appeared (at first, unexpectedly) on the yellow sign during trials 33-48.

Rationale and Predictions

The critical information collected from the experimental group focused upon the relative performance of the participants on trial #33. This was the very first time that the participants in the experimental group were presented with the fluorescent colored stimulus. Hence, it is the one and only trial where bottom-up attraction of attention due to the appearance of the fluorescent color can be assessed independently from any top-down strategic allocation of attention. Since on all subsequent trials the up-arrow search target always appeared on the fluorescent colored sign certain trends in the relative response times on trials 33-48 can also be predicted (see **Figures 2a-c**).

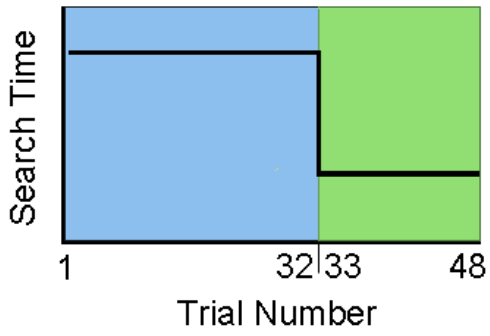

Figure 2a. Change in search time expected if the fluorescent colored target "grabs" attention via a bottom-up/preattentive process. Note the sizable and immediate reduction in search time predicted for trial #33. Subsequent maintenance of improved search times would be expected due to the combined influences of either bottom-up "attraction" and/or top-down changes in expectancy.

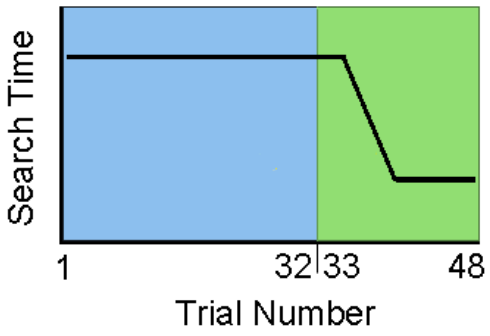

Figure 2b. Change in search time expected if fluorescent colored target facilitates search via top-down rather than bottom-up mechanisms. Note that no improvement in search time would occur for critical trial #33. However, if the fluorescent target is salient enough to "guide" visual search, top-down expectancy effects would develop over a few trials leading to a new and improved performance asymptote.

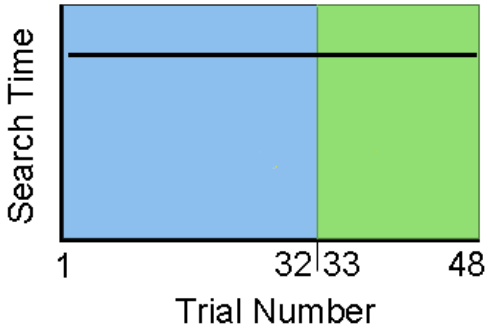

Figure 2c. Search time performance predicted if the color of the target on trials 33-48 is not salient enough to engage either bottom-up or top-down selective attention mechanisms that support improvements in search efficiency.

Results from Experiment 1

Search time data from Experiment 1 were computed for all trials yielding a correct response for the spatial localization of the up-arrow target (Less than 2% of the trials had to be edited due to performance errors). These results are depicted in **Figure 3**. Visual inspection of the data clearly reveals that search time performance on **critical trial #33** was entirely consistent with the best-fit linear regression for trials 1-32. The "abrupt" improvement that would be expected on trial #33 if the fluorescent yellow-green colored sign was recruiting the focus of attention via a bottom-up/preattentive mechanism failed to materialize. Instead, one observes a "more gradual" improvement in search performance across trials 33-36 in a manner more consistent with the development of

top-down strategies (i.e., expectancy guided selective attention mechanisms). It is also interesting to note that the standard deviation for search times observed on trial #33 did not differ from those of previous trials. Interrupted time-series analyses were used to correct the linear trends apparent in the pre- and post-trial 33 search time data with a subsequent comparison of the static performance differences resulting from the introduction of the fluorescent colored stimulus. As a result, a significant reduction in search time on the order of 300 msec could be attributed to top-down guidance of selective attention mechanisms in the presence of an "expected" fluorescent yellow-green target.

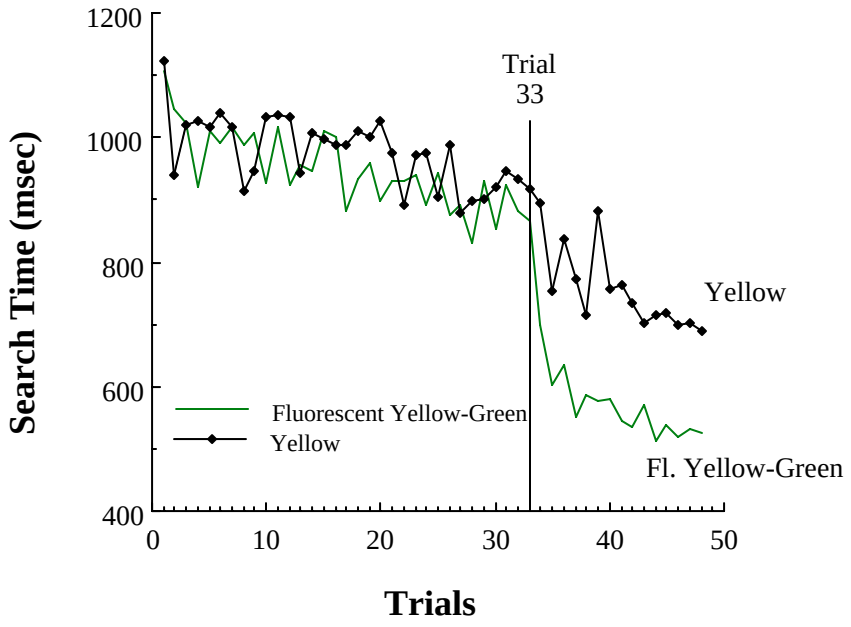

Figure 3. Search time performance for the experimental and control groups from Experiment 1. Note that the performance or the experimental group for critical trial #33 fails to demonstrate the sudden incremental improvement predicted by a bottom-up mediator of attentional conspicuity for fluorescent colored targets.

A similar analysis of the data from the control group was conducted. The data from the control group are a bit more "noisy" that those obtained from the experimental group owing to the reduced number of subjects [*Note*: We are currently collecting addition data and plan to increase the sample size from 30 to 42]. Nonetheless, it is apparent that the fluorescent yellow-green sign afforded a substantial improvement in search time relative to its non-fluorescent yellow counterpart. Interrupted time-series analyses indicated that the asymptotic performance levels (ω) achieved during trials 33-48 (corrected for linear trend) improved for the case of the fluorescent yellow-green sign relative to the non-fluorescent yellow control sign. Also of interest is the fact that the overall rates at which

the post-intervention performance levels reached asymptote appeared to be similar across both stimulus conditions. These comparable rates of improvement across the final 10 stimulus trials suggest that the observers in both conditions relied upon similar "cognitive" mechanisms to infer (and apply) the "new rule" for optimizing their search. Once this rule was "inferred" the sensory signature provided by the yellow stimulus - against the multicolored array of distracters - appeared to provide for a much less efficient top-down search process than the fluorescent yellow-green target employed in the experimental condition (as evidenced by the 200 msec difference in search times achieved during trials 41-48 across conditions).

Experiment 2
Generalization to Other Fluorescent Colors

In order to apply the results presented above to the broader class of fluorescent colors in general, the fluorescent yellow-green experimental condition was replicated using two additional fluorescent colored stimuli: namely, fluorescent red and fluorescent yellow (see Table 2).

Table 2. Photometric Properties of Fluorescent Colored Stimuli of Experiment 2.

		CIE 1931	
Background	Luminance	Chromaticity	
Color	(cd/m^2)	x	y
Fluorescent Red	17.74	0.586	0.603
Fluorescent Yellow	36.55	0.489	0.447

Participants. Two separate groups of 42 subjects each (age range: 18-30 years) served as subjects for the fluorescent red and fluorescent yellow experimental conditions, respectively. None of the subjects participated in Experiment 1.

Procedure. The experimental details of both the fluorescent red and fluorescent yellow conditions were identical to the procedure employed in the fluorescent yellow-green condition of Experiment 1 (described above). Again, the change in performance (or lack thereof) observed on trial 33 served as the critical focus of the experimental analysis.

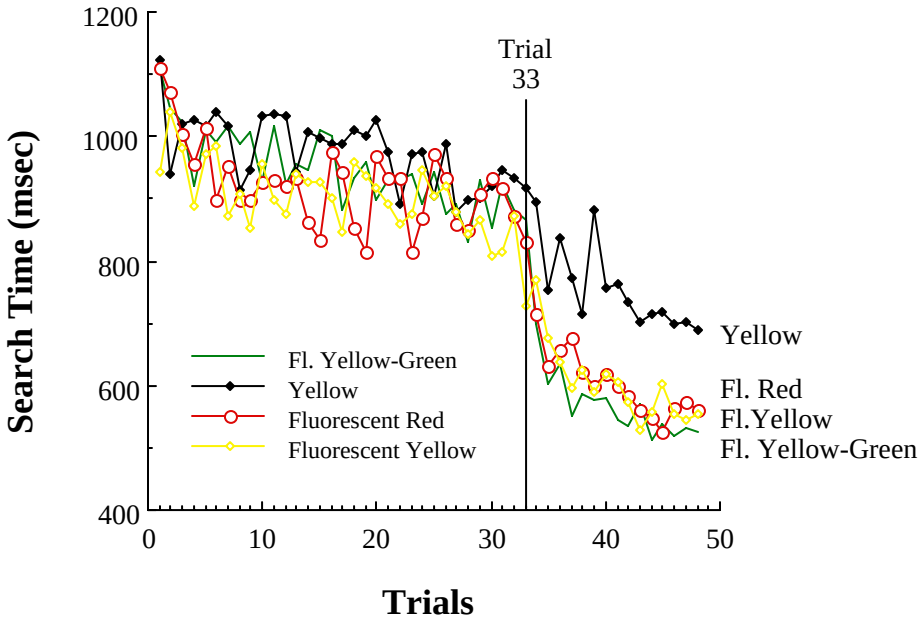

Figure 4. Search time performance for all conditions observed across Experiments 1 and 2. Note the "gradual" rather than "sudden" increment in performance observed on trials 33 through 48 for all three fluorescent colors - a pattern indicative of top-down rather than bottom-up mechanisms.

Results and General Discussion

The search time data from both Experiments 1 and 2 are depicted in Figure 4. The same pattern of performance previously observed for fluorescent yellow-green targets was replicated with both the fluorescent red and fluorescent yellow targets examined in Experiment 2. Hence, a common pattern of performance emerged for all of the fluorescent colored materials investigated. Namely, fluorescent colors provide for improved search conspicuity; and, this advantage was mediated by top-down cognitive processes.

Several aspects of the data collected in Experiment 2 are particularly noteworthy. First, the fluorescent red target provided superior performance to the yellow control condition despite the fact that the luminance of the yellow sign exceeded that of its fluorescent red counterpart (i.e., 17.74 vs. 18.88 cd/m^2). Hence, the search conspicuity advantage of the fluorescent colored signs cannot be attributed solely to concomitant increases in luminance. Second, the fluorescent yellow sign generated a performance curve that was virtually identical to the other two fluorescent colors despite the fact that the “subjective appearance” of the fluorescent yellow sign is relatively unremarkable. That is, both the fluorescent red and fluorescent yellow-green signs are routinely judged to be

exceptionally "vivid" or "uncanny" in appearance while fluorescent yellow yields neither subjective response. Hence, profound differences in the subjective appearance of different fluorescent colors failed to be associated with differences in search conspicuity as assessed in the current set of experiments. These complex roles of luminance and subjective appearance in the mediation of fluorescent color conspicuity effects are discussed at greater length by Schieber (2001).

Clearly additional experiments will be needed in order to fully understand the independent and interacting roles of luminance, color contrast and subjective appearance in mediating the visual search advantages of fluorescent colored highway signs. The preliminary work demonstrated herein suggests that such advantages involve a complex combination of both bottom-up perceptual processes as well as top-down cognitive processes. As such, it has been concluded that fluorescent colored highway signs do not automatically "grab" attention (like a flashing light). Instead, fluorescent colors provide a distinctive perceptual signal that can, with top-down intervention, "guide" attention to achieve superior search performance. It appears, therefore, that fluorescent colored signs have improved "search conspicuity" but not necessarily improved "attention conspicuity".

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