# EYE GAZE BEHAVIOR AND THE CONSPICUITY OF FLUORESCENT COLORED HIGHWAY SIGNS: DISCRIMINATING BETWEEN BOTTOM-UP VERSUS TOP-DOWN MECHANISMS OF ATTENTION IN VISUAL SEARCH

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# ABSTRACT

Eye gaze behavior utilizing an eye-tracking device was used to directly examine the bottom-up attentional conspicuity of fluorescent colored road signs. Many researchers have suggested that fluorescent colored road signs reliably capture the attention of otherwise unsuspecting drivers. This has been a widely held assumption which, until now, had not been adequately demonstrated experimentally. Twenty-four participants aged 18-35 were observed. A flashing LED sign was used to provide a ground truth reference known to attract visual attention. It was suggested that this would attract greater priority eye gaze fixations than a fluorescent yellow-green stimulus. Current research suggests this is not the case and that fluorescent colored materials have the potential to attract visual attention using bottom-up mechanisms.

# INTRODUCTION

Recent technological advances have permitted fluorescent colored materials to be economically and broadly applied to the nation's highway sign infrastructure. Research indicates that fluorescent colored highway signs may benefit from several key safety and performance-related advantages, including: (1) improved conspicuity, (2) longer legibility distances and (3) the ability to automatically attract the attention of otherwise inattentive drivers. However, the last of these claims – that fluorescent colored signs "grab" one's attention – has not been convincingly demonstrated using experimental techniques. The study proposed in the following pages represents a continuation of a programmatic effort to determine the underlying mechanisms by which fluorescent colored stimuli influence the regulation of visual attention.

## Understanding Fluorescent Colored Materials

The human eye has three different types of cones that can detect wavelengths of light in the range of approximately 400-700 nm, which is a very small region of the entire electromagnetic spectrum (see Figure 1). With this being stated, the standard tool used for identifying and determining color in the surface transportation world is the CIE 1931 color chromaticity diagram. Fluorescent colors can be mapped to exact coordinates in color space. Represented in Table 1, Burns & Pavelka (1995) cited the exact color coordinates under $D_{65}$ illumination of the fluorescent and non-fluorescent colored sign sheeting materials used in traffic safety. Figure 2 depicts the location of these values in the CIE-1931 chromaticity diagram.

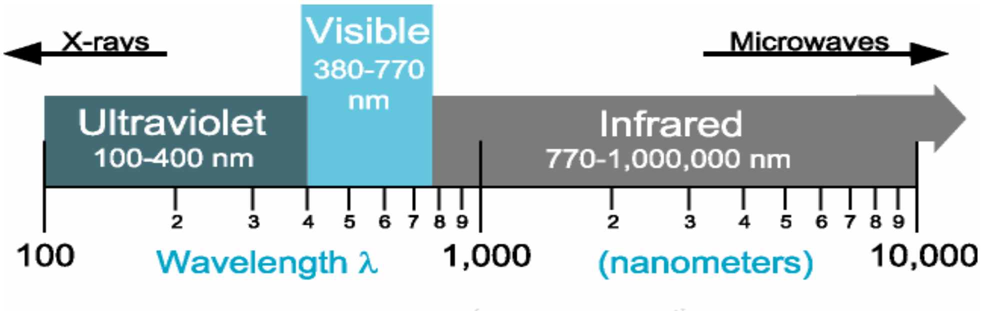


**Figure 1.** Showing the small portion of electromagnetic radiation of which humans can see (Ryer, 1998).

| Target | % *Y* | *x* | *y* |
|---|---|---|---|
| Orange | | | |
| -Durable fluorescent | 38.3 | 0.613 | 0.376 |
| -Highway traffic | 16.6 | 0.605 | 0.392 |
| Red | | | |
| -Durable fluorescent | 20.03 | 0.649 | 0.325 |
| -Highway traffic | 5.8 | 0.655 | 0.320 |
| Yellow | | | |
| -Durable fluorescent | 73.6 | 0.506 | 0.484 |
| -Highway traffic | 26.1 | 0.534 | 0.457 |
| Yellow green | | | |
| -Durable fluorescent | 86.3 | 0.398 | 0.576 |
| -Reserved | 36.6 | 0.341 | 0.510 |
| Highway traffic green | 5.9 | 0.126 | 0.418 |

**Table 1.** Chromaticity coordinates of standard and fluorescent colored signing materials (Burns & Pavelka, 1995).

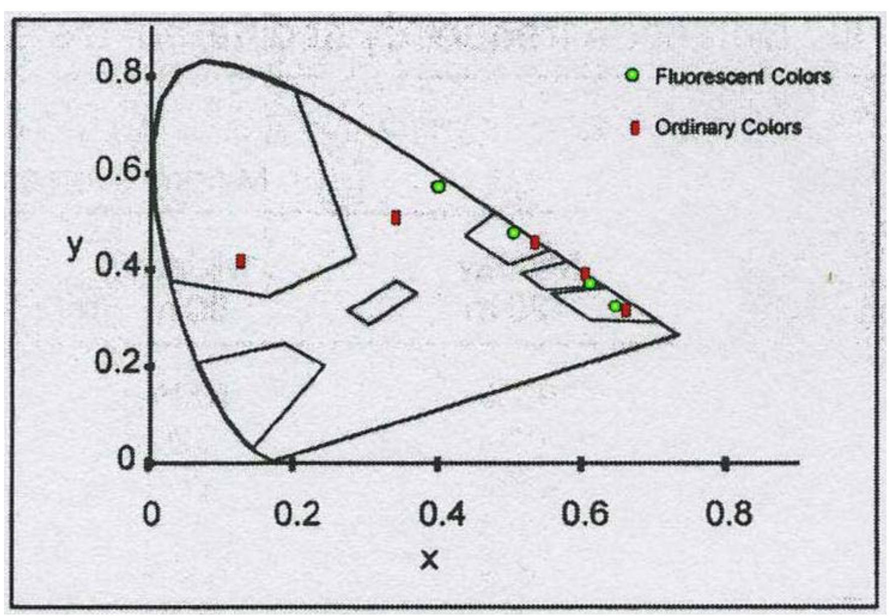


**Figure 2.** Chromaticity coordinates of fluorescent colors and standard non-fluorescent colors mapped on the CIE (1931) chromaticity diagram (Burns & Pavelka, 1995).

Typically, the appearance of “fluorescence” occurs because short wavelength light is absorbed and then re-emitted as longer wavelength light (see Figure 3). This gives the fluorescent colored material the appearance they are glowing (so-called *farbenglut*). Fluorescent signing materials have been around for approximately 40 years but until recently, long term durability was not possible. This was because the early fluorescent photopigments absorbed light below 400nm, and then re-emitted the light at higher wavelengths in the visual spectrum (between 400-700nm). However, the organic photopigments used to create the fluorescent signs would break down very quickly under the bright ultraviolet (i.e., less than 400 nm) sun exposure. This meant that the fluorescent signs could only be used for a short period of time (from a few months up to 2 years) at their peak potential depending on the environment. Within this very short amount of time the ultraviolet rays of the sun would break down the photopigments rendering the fluorescent materials ineffective. This problem resulted in the need for frequent and costly replacement of early fluorescent colored signs. If a state wanted to keep its signs fresh and up-to-date, the cost to the Department of Transportation (DOT) would be excessive. Thus, solving the problem was critical to offload DOT budgets. The answer to this dilemma would come in the form of synthetic inorganic fluorescent photopigments rather than the conventional organic photopigments.

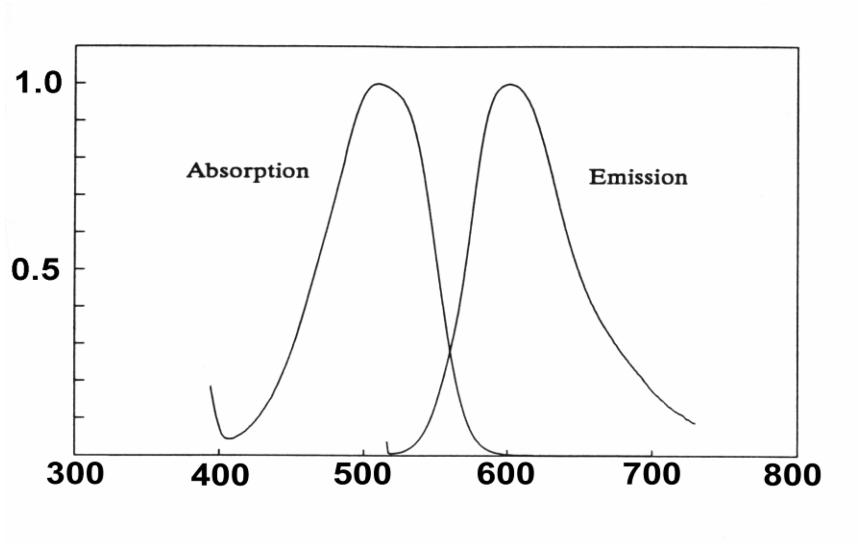


**Figure 3.** Short wavelength light reemitted as longer wavelength light (Burns, Johnson, & Pavelka, 1995).

Over the course of the past few decades road sign technology has advanced by leaps and bounds. Synthetic inorganic fluorescent photopigments used in road signs now have the ability to withstand and endure the everyday harsh environment. Because of the resilient nature of these durable fluorescent road signs they have the ability to far outlast their predecessors in terms of years, not weeks or months. As will be demonstrated shortly, these durable fluorescent colored road signs may be effective for as long as eight years.

**Visibility of Fluorescent Traffic Signs: The Early Studies**

A study conducted by Burns & Pavelka (1993) compared the performance of conventional fluorescent and retroreflective sign sheeting materials with durable fluorescent retroreflective sign sheeting materials. They positioned these different sign sheeting materials at a 45° angle facing south so as to weather and age in the harsh environment. Analyzing the signs one year later, the researchers found that the durable fluorescent sheeting materials held up well but the conventional fluorescent sheeting materials faded exceedingly. A similar study by Burns, Johnson, & Pavelka (1995) tested three different sign sheeting materials coinciding with the previous findings. The materials tested included a conventional fluorescent sign material with a durable fluorescent and durable non-fluorescent retroreflective sign sheeting. The sheeting materials were again left outside exposed to the Arizona sun facing south over the course of six months. The researchers found that the performance of the standard conventional sheeting dropped by 76%, but the durable fluorescent material lost only 19% of its original fluorescence. From these results it is clear that the durable fluorescent signing materials far out perform their conventional non-durable counterparts. Similar findings have also been reported by Hawkins, Carlson, & Elmquist (1999).

The robust performance of these improved photopigments provided a remarkable increase in resilience to the harsh environment. These synthetic inorganic fluorescent photopigments increase sign functionality from just a few months to a minimum of several years. Burns & Pavelka (1993) acknowledged that because of the improvement in resiliency to the elements, the durable fluorescent signing materials may achieve four to eight years of effective performance.

Since it is essential for traffic signs to function effectively day and night in any complex road environment, under all types of weather conditions; Burns & Donahue (2001) measured the photometric performance of fluorescent and non-fluorescent road signs both in the field and in the laboratory. They obtained both daytime and nighttime color measurements with all of the daylight measurements taken at midday under clear or overcast skies with either direct sunlight or light rain. The data collected at night was taken just before dusk with low beam illumination. Their results indicate that there is a considerable difference between the daytime luminance of fluorescent signing materials compared to the conventional signing materials. The authors also noted that it should be possible for the fluorescent signing materials to be read from further distances because of the increased contrast.

Researchers have demonstrated that daytime conspicuity of fluorescent traffic signs are better than ordinary standard colored traffic signs. In addition, they have shown that fluorescent sheeting seems to be much easier to identify at dusk as compared to non-fluorescent colored sheeting. To understand this phenomenon Burns & Johnson (1995) completed a study determining the spectral radiances of both fluorescent and non-fluorescent colored stimuli under real world conditions. The focus of the study was to determine if the appearance of fluorescent colors was simply a perceptual occurrence or if there was a measurable photometric basis for the experience. They were also interested in why fluorescent colors appear brighter during cloudy or overcast days. The authors concluded that as the day moves toward twilight, the spectral radiance of skylight shifts toward the blue end of the color spectrum. Since fluorescent colored highway signs absorb blue light and re-emit that same light at a higher wavelength, this makes fluorescent colored highway signs appear much brighter on cloudy and overcast days than a non-fluorescent sign. Hence, this phenomenon of fluorescent colors appearing to glow (so called *farbenglut*) is not a mysterious illusion but an actual measurable experience. Fluorescent traffic signs appear to have a much higher luminance and legibility contrast than their standard colored counterparts. For this reason, a number of studies have been conducted to explore the psychophysical properties of these signs under real world conditions.

The first of a four-part series of studies completed by Jenssen, et al. (1995) involved looking at the *Visibility of Fluorescent Retroreflective Traffic Control Devices*. This experiment compared combinations of rectangular fluorescent and non-fluorescent colored stimuli against a green/brown background and a blue/white background. These two different backgrounds were used to simulate either a rural setting or the sky, snow, and/or ice, respectively. An expert panel was assembled to view the different colored stimuli both in daylight and at night. The expert panel provided information to the researchers in three areas which are as follows: (1) the noticeable distinction of fluorescent colored signing materials compared to non-fluorescent conventional black and white, (2) the increased legibility distance of fluorescent colored sheeting compared to non-fluorescent sheeting, and (3) the subjective rating of the background color pertaining to sign contrast and legibility. The researchers concluded that across all the different color combinations, lighting conditions, and background scenes, seven of the top ten performers included a fluorescent background with non-fluorescent foreground legend. They also concluded that the fluorescent yellow-green sheeting material with black lettering was the best overall color combination.

A survey by Dutt, Hummer, & Clark (1996) also asked participants to provide their subjective rating to mid-block pedestrian intersections which utilized fluorescent yellow-green warning signs. In evaluating the 1220 usable responses, drivers rated the fluorescent yellow-green pedestrian warning signs as outperforming their non-fluorescent counterparts in terms of conspicuity. The survey also found that 70% of the respondent indicated a better overall awareness to pedestrians when a fluorescent yellow-green pedestrian sign was used. Also, 76% thought the fluorescent yellow-green sign was more effective than the standard non-fluorescent traffic sign.

A laboratory study completed by Dutt, Hummer, Clark, & Blakely (1995) tested both fluorescent and non-fluorescent pedestrian crossing signs and curve-ahead road traffic signs. Five different background environments were also used: bright daylight, washout from front lighting by the sun, backlighting from the sun, twilight, and a complex background simulating a busy commercial area. The experimenters concluded, in agreement with various other researchers that the use of fluorescent yellow-green sign sheeting material outperformed the non-fluorescent counter part in terms of legibility distance.

The second of a four-part study completed by Jenssen, et al. (1996) looked at the *Visual Performance of Fluorescent Retroreflective Traffic Control Devices*. Again, as in the first of the series, this study used fluorescent and non-fluorescent colored signs and controlled for both day and night observation. This experiment went a step further and used not only young but elderly participants. The researchers examined the distances at which participants could detect signs, if the legend was symbol or text, if they could recognize the shape of the sign, and if they recognized the color of the signs presented to them. A straight section of railroad was used with the participants being pushed in a rail car viewing life-sized traffic signs mounted on a 3-4 kilometer stretch of track. The results show that young and older drivers have a statistically significant longer detection distance for fluorescent signs than non-fluorescent signs in both day and night conditions. Along with the previous finding they concluded the fluorescent colored sign sheeting is recognized from further distances than non-fluorescent colored sign sheeting. They also found that both younger and older drivers recognize the shape of fluorescent signs earlier as compared to non-fluorescent signs; i.e., 79 meters and 92 meters, respectively.

Burns & Pavelka (1993) discussed a study they conducted the previous year looking at the daytime conspicuity of fluorescent traffic sign colors in comparison to the standard highway colored traffic signs. Participants viewed circular stimuli, paired up by one fluorescent with one non-fluorescent. Four separate viewing distances were used beginning at 120 meters and moving closer to the signs. Also, two different background colors were used; bright white and camouflage (greenish-brown). Each participant viewed pairs of stimuli for “2 seconds by means of an electronic shutter system” (p. 7). The researchers concluded that participants identified fluorescent colored materials from further distances than non-fluorescent counterparts. They also found that the visibility and conspicuity of fluorescent colored materials are two to three times that of non-fluorescent colored signing materials.

In 1995 Burns & Pavelka conducted a follow-up study to their 1993 investigation, comparing the detection, color recognition, and conspicuity of fluorescent colored traffic signs to their non-fluorescent standard counterparts. Again, circular stimuli were compared in pairs, one fluorescent with one standard color, against a complex camouflage background at midday and dusk. The outcome of the experiment showed that the fluorescent materials were identified at greater distances than the standard colored materials. Burns & Pavelka also concluded that the standard colors yellow and orange were detected by less than half of the observers at the greatest test distance, whereas that the corresponding fluorescent signing materials, at the same distance, were identified more than 90% of the time. The following figures show this very point, that the fluorescent colored signing materials are detected and recognized more often at greater distances than their non-fluorescent counterparts.

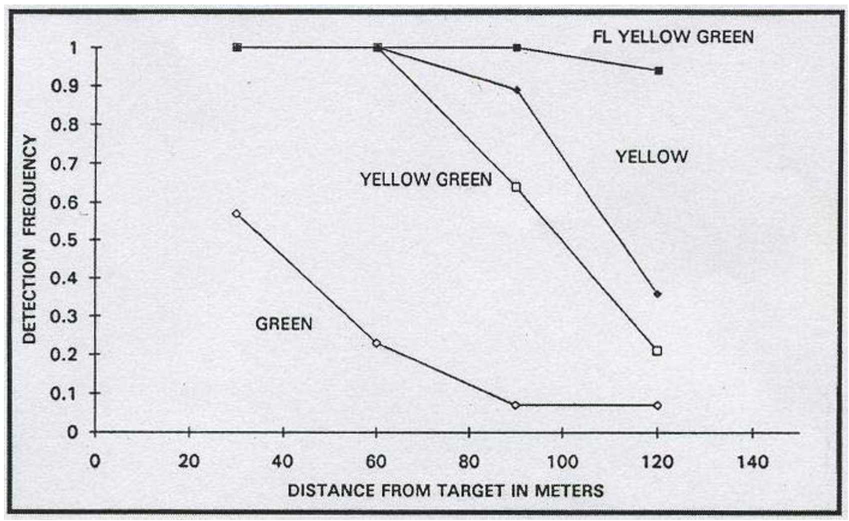


**Figure 4.** Probability of correct detection as a function of distance from the target for fluorescent yellow-green compared to non-fluorescent yellow, green, and yellow-green targets (Burns & Pavelka, 1995).

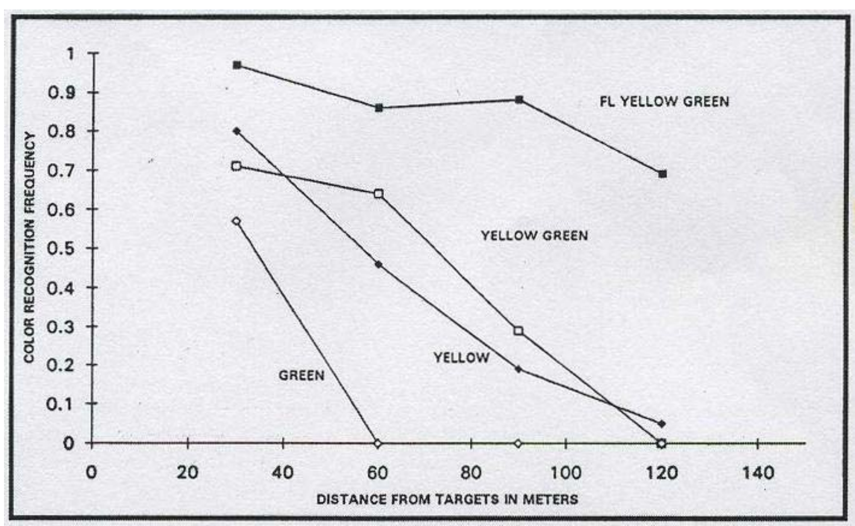


**Figure 5.** Probability of correct color recognition as a function of distance from the target for fluorescent yellow-green compared to non-fluorescent yellow, green, and yellow-green targets (Burns & Pavelka, 1995).

It is apparent that targets with fluorescent colored sheeting can be recognized easier and seen at greater distances from straight ahead than ordinary standard colors. The next question to be answered is: Can these same signs be detected better in the visual periphery? To answer this question Zwahlen & Devi Vel (1992) conducted a study where participants used their peripheral vision while viewing fluorescent and non-fluorescent colored targets. The participants sat behind the wheel of a car at 100 feet and observed the colored stimuli against three different background scenes: a typical city scene, fall foliage scene, or spring foliage scene. The authors concluded that fluorescent yellow was better detected at the peripheral angles of 20, 30, and 40 degrees.

A few years later, Zwahlen & Schnell (1997) presented a very similar daytime study where participants again used their peripheral vision to inspect fluorescent and non-fluorescent colored targets. Each colored stimulus was presented off-axis and to the right of the participant's field of view in front of a green background. It was the authors' intent that this study might be helpful in understanding if fluorescent colored signing materials would be beneficial for bicyclists, pedestrians, or road construction workers, especially if they come from the driver's left or right periphery in an intersection or construction zone. Again, their results showed that the fluorescent road sign sheeting materials compared to their non-fluorescent color counterparts are superior in terms of detection in the visual periphery.

**Traffic Engineering Research Using Fluorescent Materials**

It comes as no surprise that fluorescent traffic signs have many advantages, but if the benefits of fluorescence do not out weigh the costs in the real world—in real driving situations—then there is no real advantage. Ultimately what must happen is a considerable change needs to take place in the behavior of the drivers at the wheel, otherwise what good is it to develop and ultimately utilize the fluorescent colored signs on the roadways? Thus, Hummer & Scheffler (1999) conducted a real world study in which driving performance through work zones were measured using both conventional standard orange and fluorescent orange sheeting materials. The results revealed that by using the fluorescent colored warning signs, constructions zones would provide a safer environment for both the workers and motorists.

Eccles & Hummer (2001) also conducted a study using a before-and-after approach by replacing existing yellow warning signs with fluorescent yellow warning signs at seven hazardous sites. The purpose of this study was to evaluate the effectiveness of fluorescent yellow warning signs in improving highway safety at hazardous locations. The results revealed that fluorescent sign sheeting materials were most beneficial at the sites where advanced warning information from the surroundings was not possible. Eccles & Hummer also concluded that even though fluorescent signs cost a few dollars more than non-fluorescent signs, the apparent benefits outweigh the costs considerably if it means drivers pay closer attention to the traffic signs and fewer traffic accidents take place.

As far as fluorescent signs being more conspicuous, Schnell, et al. (2001a) conducted a real-world study looking at fluorescent and non-fluorescent traffic signs. It was hypothesizing that drivers who were accustomed to looking at fluorescent yellow-green pedestrian signs would make fewer eye fixations to them as compared to drivers who were not accustomed to seeing the fluorescent yellow-green signs. The authors were hypothesizing that the “novelty advantage” of fluorescent yellow-green pedestrian signs would fade over time. An eye-tracking system was used to examine the number of eye fixations per traffic sign. It was found that the fluorescent yellow-green school zones signs captured the attention of the motorists more often than did the standard yellow colored signs. The researchers concluded that the predicted fading of the novelty-based advantage of the fluorescent yellow-green signs does not occur.

Schnell, et al. (2001b) presented another paper that year looking at the *Legibility Distances of Fluorescent Traffic Signs and their Normal Color Counterparts*. This experiment was conducted to see if adding fluorescent photopigments to traffic signs does indeed increase legibility distance. This investigation, as in his previous work, was a daytime study which used a somewhat dynamic driving situation looking at fluorescent and non-fluorescent colored traffic signs. The results showed a small but statistically significant increase in legibility distance when adding the property of fluorescence to the road signs. The researchers concluded that the fluorescent colored signing materials compared to non-fluorescent colored signing materials were superior in detection and recognition.

**Other Areas Fluorescent Materials May Play a Role**

Fluorescent colors also play a major role not only in traffic signing materials but in road worker safety vests as well. Sayer & Mefford (2000) conducted an experiment examining both young and older participants in static daytime and nighttime driving conditions. The task was a side-by-side comparison of possible fluorescent sheeting materials with retroreflective trim for road worker safety vests. Low-beam headlights were used for illumination in the nighttime condition. The researchers found that the stimuli which were most noticeable had two attributes in common: (1) each contained either a fluorescent orange trim or orange base material, and (2) trim and base materials did not match. These findings suggest that road workers must not only to be noticed, but also recognized. That is, it needs to be very clear that a person is a person and a cone or a barrel is not human.

The use of fluorescent colors in sign sheeting and road worker vests is of great importance, but other areas of transportation can benefit as well. Solomon & King (1997) were interested in the question of whether fire truck color made a difference in the frequency of accidents based on driver visibility. The researchers reviewed traffic statistics between 1984 and 1988 from Dallas, Texas, which showed the use of fluorescent lime-yellow/white paint on fire trucks was safer than those fire trucks that were painted red or red/white. They also stated that the probability of an accident was three times as likely to occur with fire trucks painted red or red/white as those painted fluorescent lime-yellow/white.

It is well known that photopic (cone) vision, which allows humans to see color, is most sensitive to light at the 555 nm wavelength (see Figure 6). Interestingly enough, it just so happens that the reflectance of the lime-yellow paint (i.e. fluorescent yellow-green) used on the fire trucks peaks near this 555 nm wavelength (see Figure 7). This may explain why the lime-yellow/white fire trucks experience a crash rate that is only one-third as great as red or red/white colored fire trucks.

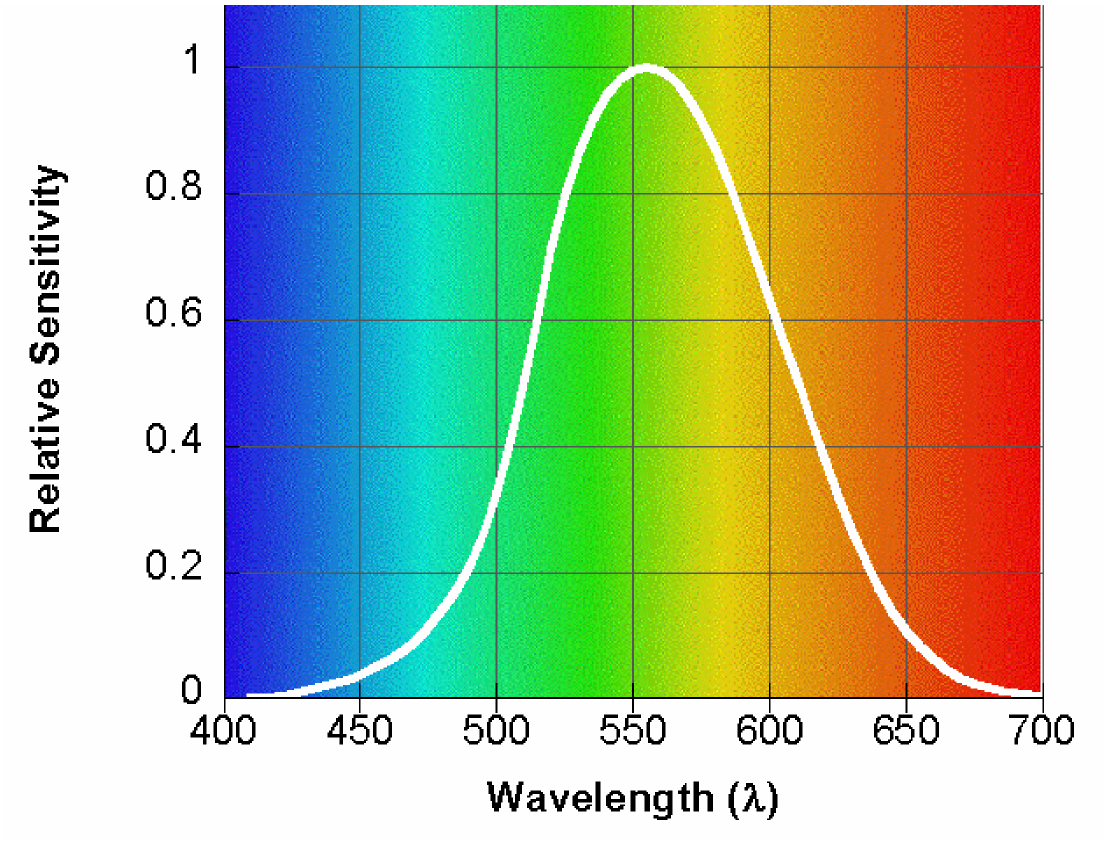


**Figure 6.** The photopic (cone vision) sensitivity curve along with apparent perception of color at each wavelength.

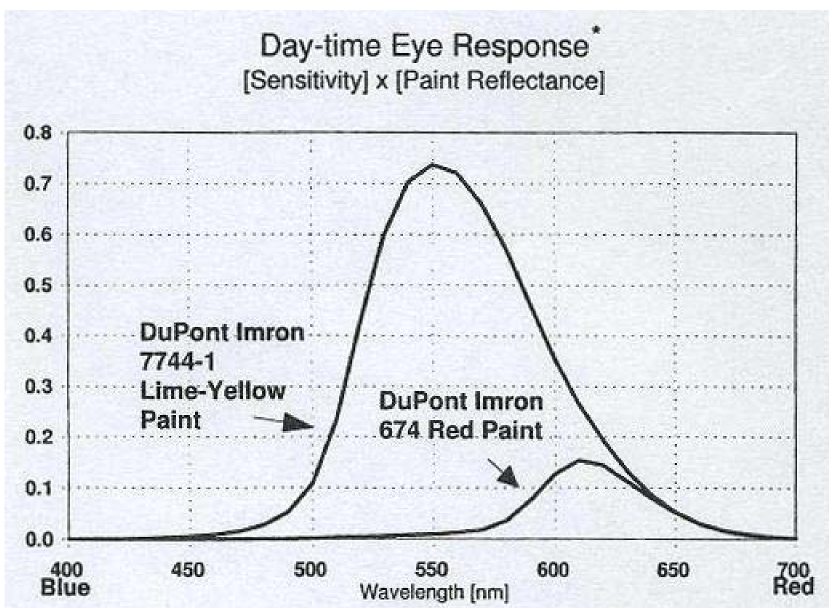


**Figure 7.** Spectral reflectance of Lime-yellow and Red paint used on fire trucks (Solomon & King, 1997).

## Visual Conspicuity

There is a strong body of literature suggesting that fluorescent colored road sign sheeting materials are more visible than their standard color counterparts. Many researchers have suggested that fluorescent colored road signs pop-out, grab, or capture attention. This is to say that fluorescent colored sign sheeting materials are more conspicuous than non-fluorescent colored sheeting material.

In the surface transportation world the visibility of road traffic signs can be classified into two main categories: conspicuity and legibility. The main focus for the remainder of this paper will be on the conspicuity of road signs. Typically when people think of conspicuity they think of something that is eye-catching and has the ability to capture the attention of the unsuspecting person because they are not actively looking for the specific object. Treisman (1986) summed up the term conspicuity by stating, “The assumption is that if the preattentive processing occurs automatically and across the visual field, a target that is distinct from its neighbors in its preattentive representation in the brain should ‘pop out’ of the display” (p. 101). However, this definition captures only a single part of the construct of conspicuity. To fully understand the definition of conspicuity it must be understood that conspicuity can be classified into two distinctly different categories: top-down/goal-directed conspicuity and bottom-up/stimulus-driven conspicuity. These two mechanisms of conspicuity will be further explained in the following paragraphs.

## Attentional Conspicuity vs. Search Conspicuity

Top-down conspicuity, also known as search conspicuity, is defined by Theeuwes (2004) as, “The ability to select those areas, objects, feature attributes, and events needed for our current tasks" (p. 65). Jenkins & Cole (1986) define this type of conspicuity as, "The ability of the traffic control device to be quickly and readily located by search" (p. 75). This type of search relies upon the observer's attentional readiness (Egeth & Yantis 1997). This is to say that, once a person knows what to search for, the time to locate the stimulus should dramatically decrease when search conspicuity is high. This does not imply that a stimulus will immediately grab attention or pop-out of the scene. In this case, the pop-out or capture of attention only occurs once the person knows exactly what they are searching for.

Bottom-up conspicuity, also known as attentional conspicuity, is defined by Theeuwes (2004) as "The capacity of certain stimulus attributes to attract our attention, irrespective of our goals and beliefs" (p. 65). Jenkins & Cole (1986) define this type of conspicuity as:

> One that will, for any given background, be seen with certainty (P > 90 percent) within a short observation time (t = 250 msec) regardless of the location of the object in relation to the line of sight…also…a conspicuous object by this definition requires no searching to be seen with certainty...Attentional conspicuity is the capacity of the traffic control device to attract attention when the driver is unaware of its likely occurrence. (p. 75)

There are only a couple classes of stimuli which research has shown to elicit a true bottom-up pop-out mechanism. These stimuli can be characterized as having a distinctive temporal signature, including motion and/or abrupt onsets. An abrupt stimulus onset is one that is characterized by a sharp temporal discontinuity in which the transition between the stimulus absent and present states is visually instantaneous (i.e., <50 msec). Both moving stimuli and abrupt onset stimuli will suddenly and unexpectedly pull the allocation of attention away from what the observer was currently viewing and cause the observer's fixation and attention to be drawn to the aforementioned stimulus.

Kramer, et al. (2001) proposed a three-part study looking at the *Influence of Single and Multiple Onset Distracters on Visual Search for Singleton Targets*. It was shown that the abrupt visual onsets captured the attention of the participants due to their increased reaction times in completing the tasks. The researchers also concluded that even when the onset stimuli are task irrelevant, they still seized the participant's attention. Yantis & Jonides (1984) reported similar findings as well, and concluded that abrupt onset stimuli captured the attention of the participants.

Abrupt visual onsets are not the only stimuli that have been reported to capture attention. Franconeri & Simons (2003) conducted a study examining the ability of moving and looming stimuli to capture attention. The authors concluded that both moving and looming stimuli captured attention as strongly as abrupt onsets even when they were not new objects.

From the previous findings one might wonder if it is the presence of a new stimulus that is capturing the attention of the participant and not the moving or looming stimulus? To answer this question Franconeri, Hollingworth, & Simons (2005) recently conducted a two part study titled *Do new objects capture attention?* asking that very question. Their results show that new objects in fact, *do not* capture attention.

**The Inattentional Blindness Paradigm**

There is a problem with trying to elicit these bottom-up/attentional processes. That is, the presentation of a presumed attention getting stimulus (i.e., abrupt onset, moving, or looming stimulus) must be unexpected. Vast amounts of literature trying to elicit a bottom-up conspicuity mechanism fail to present participants with a sudden and unexpected stimulus. In most cases the participants already know what the pop-out/attention grabbing stimuli look like or the pop-out/attention grabbing stimulus is presented multiple times. This allows participants to form explicit expectations about the nature of the stimulus. Many times with experiments trying to elicit strictly bottom-up attentional mechanisms participants are expecting something, and because of their expectations, this defines where they focus visually. Hence, if participants know what to look for or ignore, they will be more inclined to look directly at those particular stimuli.

This is not the first time it has been recognized that it is difficult to conduct experiments that only elicit bottom-up/attentional mechanisms; Egeth & Yantis (1997) proposed a similar dilemma. The authors explained that numerous experiments have been conducted which do not completely cancel out top-down influences and focus on bottom-up search mechanisms. Thus, it is imperative to design experiments which separate top-down search mechanisms from bottom-up mechanisms. This is to say that, in order to isolate a bottom-up mechanism of attentional conspicuity an experiment has to include a sudden and unexpected presentation of the “pop-out” trial, where the participant has absolutely no prior knowledge about the critical stimulus.

In accordance with the above statements, Mack & Rock (1998) took on the challenge to develop an experimental paradigm which would hopefully ascertain a clear boundary between an experiment that elicits solely bottom-up mechanisms of attention from those which elicit top-down plus bottom-up attentional mechanisms. The researchers also thought it would be necessary to utilize some sort of distraction task to employ the participant's attention to a specific location. The paradigm they devised is called an *Inattentional Blindness* paradigm. This experiment asked the question, 'Does looking at an object necessarily mean a person's attention is fixated on that object?' Mack & Rock conducted a very simple Inattentional Blindness experiment to answer this question. In the experiment participants focused on a small center fixation cross and then the presentation of a large cross, roughly 2 degrees off-axis from the participants' central fixation, was displayed for 200 msec. After which, a mask was displayed for 500 msec (see Figure 8). The mask was presented to eliminate any processing of the visual display after the large cross disappeared from the screen. Since the presentation of the large cross was only displayed for a very short period of time, this would not allow observers enough time to make a saccade anywhere else in the visual perimeter. A saccade is defined as a ballistic transition of the eyes from one fixation to another. After the 500 msec display of the mask the participants were asked to report which arm of the cross appeared longer. This same protocol was followed for the first two or three trials and then a special "critical" trial was presented. In the critical trial the same large target cross was displayed roughly 2 degrees off-axis but also, a small stimulus was presented in the middle of the screen in the same location as the center fixation cross. This is to say that the small stimulus was in the exact location of the participant's fixation (see Figure 9).

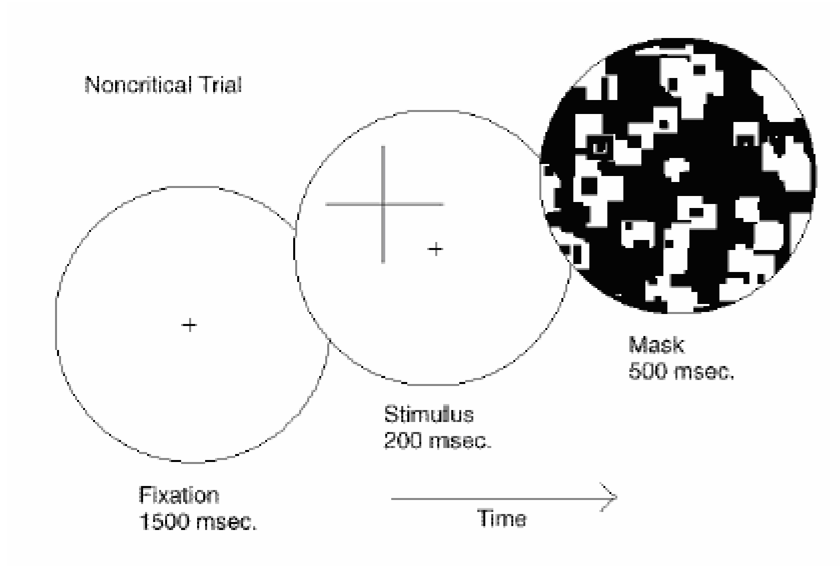


**Figure 8.** The non-critical trial in the inattentional blindness paradigm for experiment 2 (Mack & Rock, 1998).

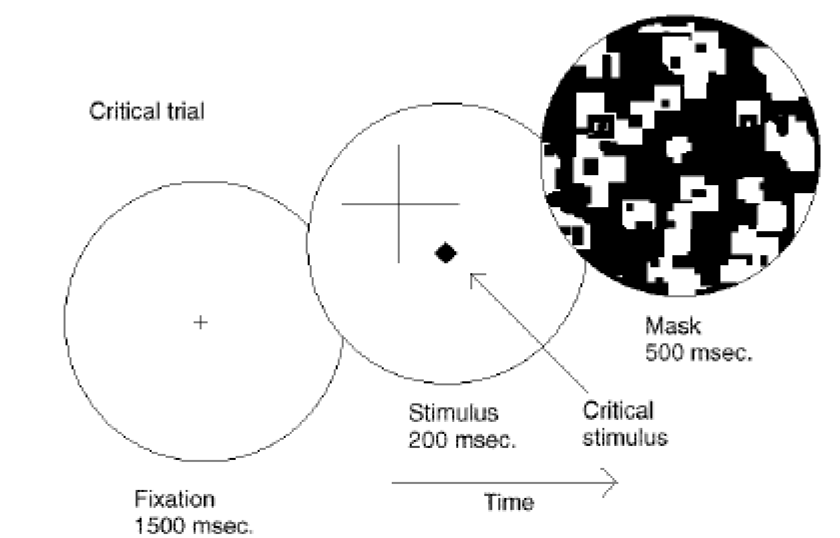


**Figure 9.** The critical trial in the inattentional blindness paradigm for experiment 2 (Mack & Rock, 1998)

Immediately following the critical trial, the experimenters asked the participants something to the effect of, "Did you see anything on the screen on this trial that had not been there on previous trials?" Surprisingly, the results for the experiment showed that between 60% and 80% of the observers failed to detect the critical stimulus. From the experiment the authors concluded that *attention has to be drawn to an object for it to be perceived consciously*.

**Do Fluorescent Colors Have Attentional Conspicuity?**

Thus far it has been shown that the added brightness of traffic sign sheeting materials provided by synthetic fluorescent photopigments is not just a perceptual marvel, but there are measurable photometric properties to explain its potential benefits. This provides an understanding as to the increased legibility distances of fluorescent sign sheeting materials compared to their ordinary color counterparts. A recent conference session held by the Transportation Research Board in 2001 concluded that fluorescent sign sheeting is more conspicuous and appears to “pop-out” from the background and (supposedly) “grab the attention” of the unsuspecting driver. Large quantities of literature all seem to concur with the assumption that fluorescent colors grab attention. But, to date, it has not been adequately demonstrated through experimentation (Schieber Larsen, Jurgensen, Werner, & Eich, 2001).

**Experiment 1**

To directly answer the question ‘Do fluorescent colors actually grab your attention?’ Schieber (2002) conducted a laboratory study with different colored stimulus signs using an inattention search paradigm (very similar to the Mack & Rock (1998) Inattentional Blindness paradigm). The sign sheeting used for each colored stimulus was either: red, yellow, orange, green, or fluorescent yellow-green. Each stimulus also contained a single black directional arrow. Each colored stimulus was randomly distributed in both placement and in cardinal direction of the stimulus arrow, either: up, down, left, or right (see Figure 10). It must be noted that Schnell, et al. (2001a) stated, "Fluorescent yellow-green probably has the best attention getting quality of all durable fluorescent traffic sign colors available today" (p. 3). Not coincidentally, this is the same colored stimulus that was used for the following experiments.

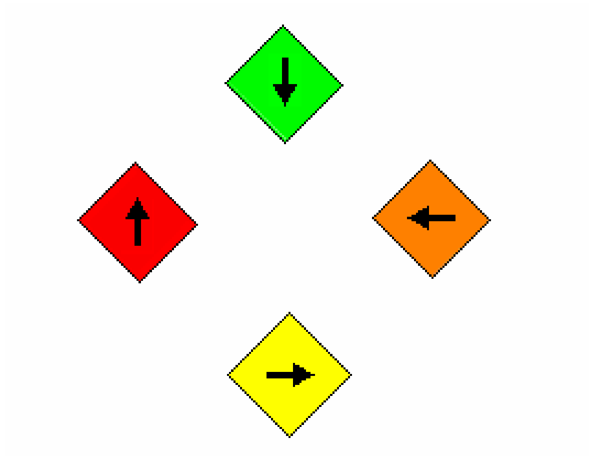

**Figure 10.** Depicting the experimental set up including directional arrows (Schieber, 2002).

For each trial the participants were presented with four different stimulus signs. The participants were told to find the "up" arrow as quickly as possible and enter their response on a key pad located on the table in front of them. The key pad contained four response buttons in the same diamond configuration as the four stimuli. For the first 32 trials, only the standard non-fluorescent colors (red, yellow, orange, and green) were used in the experiment. Then on trial 33, without the participant's knowledge, the standard non-fluorescent yellow stimulus was removed from the mix and the fluorescent yellow-green stimulus was inserted. Randomization of the placement of stimuli and cardinal directions of the arrows remained the same; however, for the remainder of the trials (trials 33 – 48) the fluorescent yellow-green stimulus was always the up arrow target of the search.

Schieber (2002) provided several hypotheses as to what the appearance of either top-down or bottom-up mechanisms would look like graphically. It was hypothesized that if fluorescent colors pop-out and grab attention, that the participant's reaction time should be discretely and significantly decreased between trials 32 & 33. The pop-out effect would support the idea of participants using a bottom-up/attentional process for the fluorescent colored target (see Figure 11).

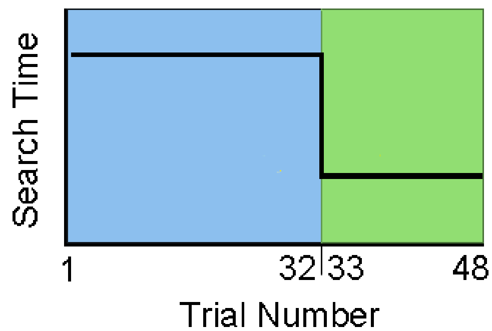


**Figure 11.** Hypothesized outcome of "bottom-up" search process. Notice that at the critical trial 33, there is a sudden and significant drop in reaction time (Schieber, 2002).

An alternative hypothesis suggests that participants are using a top-down/search process for the fluorescent colored target (see Figure 12). The performance curve predicted by this assumption shows that when the fluorescent yellow-green stimulus is unexpectedly presented it does not pop-out. The reaction time does not drop sharply at the critical trial 33 but instead, gradually declines between trials 33-48, thus indicating a top-down search process rather than a bottom-up process. This would support the notion that the fluorescent colored singleton was guiding attention rather than grabbing attention. That is, the fluorescent colored stimulus was hypothesized to guide attention rather than grab attention simply because, as Figure 12 shows, once a participant developed a sense of what they were looking for, they could spot it (the fluorescent singleton) with improved efficiency. Hence, a gradual decrease in reaction time would result.

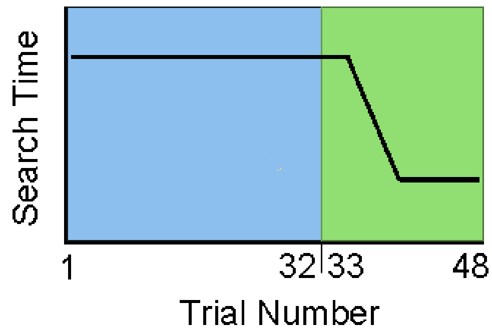


**Figure 12.** Hypothesized outcome of "top-down" search process. Notice that at the critical trial 33, there is not a sudden drop in reaction time, but a gradual decrease (Schieber, 2002).

The actual results obtained revealed that there was a slight learning effect between trials 1-32, but that on the critical trial 33, the unexpected presentation of the fluorescent yellow-green stimulus failed to grab attention (see Figure 13). The dramatic shift in reaction time was not apparent on critical trial 33; but, instead, a gradual improvement of reaction time was seen (consistent with previous Figure 12) between trials 33-48.

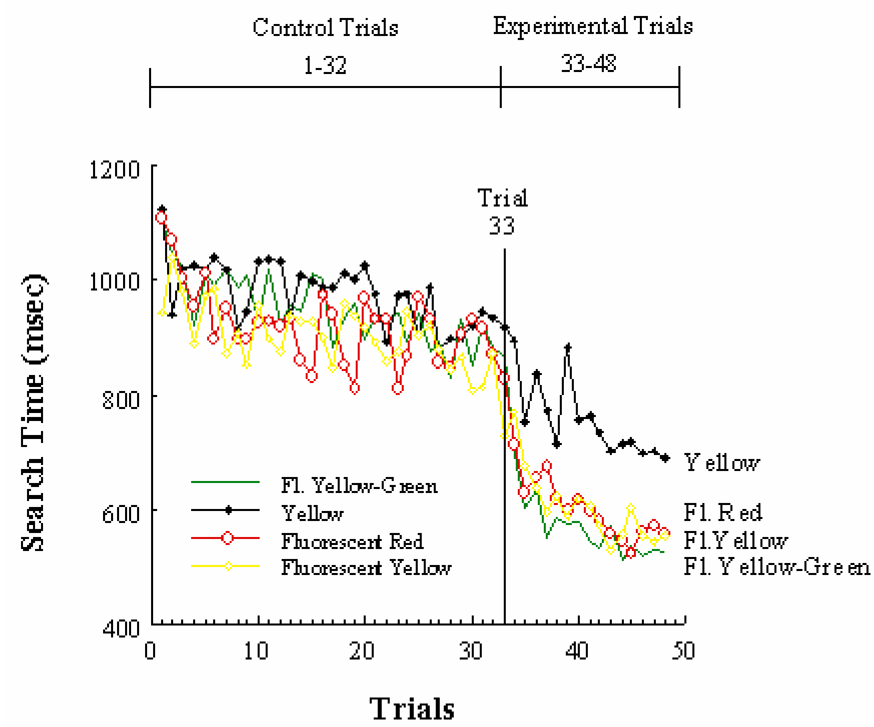


**Figure 13.** Reaction time curves for different fluorescent colored singleton experiments: red, yellow, and yellow-green compared to the standard non-fluorescent yellow used as a control in the 1st experiment. (Schieber, 2002).

## Experiment 2

A second series of inattention search experiments were conducted. The second inattention search paradigm was a replication of the first but instead of using fluorescent yellow-green, fluorescent red or fluorescent yellow were used. The same protocol was employed, i.e. replacing the standard non-fluorescent stimulus with the fluorescent stimulus. The results showed the same gradual improvement rather than discrete improvement of reaction time for the fluorescent red and fluorescent yellow stimuli for trials 33-48 (see previous Figure 13).

**Alternative Explanation for Experiments 1 & 2**

One explanation of these results is that fluorescent colored stimuli possess strong search conspicuity but are completely lacking in attention conspicuity. Unfortunately, there is also another explanation that is compatible with the results obtained. There is a remote possibility that a suppression of color information was being developed throughout the first 32 trials. That is, since color information was not necessary to efficiently locate the up arrow target, the participants may have learned to actively suppress the potentially distracting color signals. Then, when the critical trial 33 occurred, no dramatic fluorescent color pop-out was seen because of this potential suppression of color information. In light of this alternative explanation it was thought that the only way to truly determine if the fluorescent colored stimulus was, in fact, grabbing attention was to use an eye-tracking device. The use of such a device would allow the experimenter to fully understand where the participant’s eyes were converging; where their attention was located; and, to directly examine spatial transitions of attention.

**Eye-Tracking**

In previous years the use of eye-tracking was done by placing a camera facing a participant’s eyes and recording the eye scanning patterns. Needless to say, incorporating eye-tracking into experiments with large numbers of participants was not widely done due to it being encumbering and time consuming for the researcher. Luckily, with the advancement of technology, eye-tracking is being more widely used in applications to better understand visual tendencies of the human. This allowed for the use of an eye-tracking device in the pilot study discussed below.

To understand why an eye tracker was used for the pilot and proposed studies, some terms need to be understood. First, an eye fixation can be characterized as the fundamental component of all visual behavior. As stated previously in the paper, each fixation is transitioned by a bullet-like trajectory of the eyes, from one location to another called a saccade. Once a person has begun a transition of a saccade very little, if any, new information can be acquired. A suppression of the visual scene occurs because as Green (2002) explains, a person's visual system continues to process information from the previous fixation. Typically in eye movement studies researchers are not only interested in eye fixations but also in total fixation time on the stimuli, also referred to as total glance time. "A glance consists of all consecutive fixations on a target plus any preceding transitions" (Green, 2002).

As Green (2002) points out, when a person rotates their eyes toward an object to fixate that object, they can move their eyes as rapidly as 275 degrees per second. This incredible rate of speed should be captured by the eye-tracking device in both the pilot and proposed studies since the target signs were directly in front of the participants and there was no need to turn their heads. Green (2002) makes note of this in his paper that if a person notices an object within 15 degrees of their line of sight a person does not need to move their head, but further than 15 degrees and head movement occurs. As will be explained later in the proposed study, an analysis was conducted looking at: (1) the order of eye gaze fixation, (2) the total glance time, and (3) the total number of fixations. This allowed the researchers to see if the proposed hypothesis is correct; namely, the question of whether fluorescent colored stimuli elicit a bottom-up/attentional conspicuity mechanism or a more top-down/search conspicuity mechanism.

**Ground Truth and Eye-Tracking**

There is still a problem even in using an eye-tracking unit to exactly replicate the 1st and 2nd experiments of Schieber (2002) described above. The problem in replicating the experiments using an eye-tracking device is that there is no "ground-truth" stimulus which has been validated to positively grab people's attention. If the researchers were to simply replicate the previous experiments they would in essence be predicting the null hypothesis. However, to address this point, a flashing sign composed of a small cluster of red, yellow, and orange light emitting diodes (LED's) was used. This special sign appeared to be a flashing yellow stimulus to the participants. Pilot research discussed in the next section, confirmed that such a flashing stimulus consistently attracted the attention of our participants, providing a validated reference condition for assessing attention conspicuity via eye movement behavior.

**Pilot Eye Movement Study of Attentional vs. Search Conspicuity**

A small scale pilot study was conducted with a similar protocol as the previous two inattention search paradigms mentioned. The same five colored stimuli were used as before, but the stimuli were void of the directional arrow. Instead of all the stimuli presented in only a diamond configuration composed of four locations, there were eight different stimulus positions. Also, in addition to the five colored stimuli, a small cluster of LED's was used to implement a flashing sign. This flashing sign presented the participants with a ground-truth stimulus for assessing bottom-up attentional attraction.

Each of the ten participants were fitted and calibrated to an Applied Science Laboratories (ASL) Model 501 head mounted eye-tracking device before the start of each experiment. Since there were no directional arrows and the participants were wearing an eye-tracking system, (allowing the experimenters to examine each individual saccade) the stimuli were presented in a randomized order for a total of five seconds on each trial. The participants were told simply to observe what was presented for each of the 10 trials. Similar to the previous two inattention search paradigms, this experiment presented participants with two critical trials. In trials 5 and 10, the participants were shown: (1) the removal of the standard non-fluorescent yellow stimulus replaced with the fluorescent yellow-green stimulus as in the previous experiments, and (2) the removal of the standard non-fluorescent yellow stimulus and its replacement with the flashing LED sign. Each participant received the fluorescent yellow-green stimulus as trial 5, and the flashing LED sign as trial 10. The results of the eye movement analysis showed not only that the fluorescent colored target failed to grab attention for the priority eye fixation, but also that there appeared to be no evidence to support the attentional conspicuity/bottom-up hypothesis for the critical fluorescent trial 5.

**Problems/Corrections of the Pilot Study**

There were some problems with the pilot study that must be addressed. First, the number of subjects and the number of stimulus trials was too small to ensure adequate statistical control and/or power. Also, the randomization of the distracter fluorescent yellow-green target and flashing LED sign location was not fully inclusive of the entire range of target mounting positions. The pilot study presented both the fluorescent yellow-green stimulus and the flashing LED sign stimuli mainly in the middle and upper target mounting positions. To ensure that the experimental stimuli will each have a fair advantage, they must be equally distributed across all the mounting positions. The experimental stimuli (fluorescent yellow-green and flashing LED sign) always occurred on trial 5 and trial 10, respectively.  These must be counter-balanced so that half of the participants receive the fluorescent target first while the other half will receive the flashing LED as the first experimental stimulus exposure.

**Summary of Fluorescent Literature**

Current literature both in the laboratory and in the field regarding synthetic inorganic fluorescent photopigments utilized in road traffic signs has established a very convincing argument.  Fluorescent colored traffic sign sheeting materials, as compared to their non-fluorescent counterparts, have been shown to be more conspicuous, provide better legibility at further distances, and even inadvertently capture an observer's attention.  Unfortunately, the last part of the previous statement has not been demonstrated adequately by experimentation.  After reviewing the literature and previous studies conducted at the University of South Dakota, I have proposed a study to hopefully explain the controversial issue of whether fluorescent colored sign sheeting actually grabs attention (from the bottom-up) or simply guides attention (from the top-down). The proposed visual search experiment will be very similar to the previously described pilot study utilizing an inattention paradigm. As mentioned earlier there were a number of problems associated with the pilot study, therefore, a number of improvements have been made and the problems corrected.

**Experimental Hypotheses**

In the proposed experiment it is hypothesized that the flashing LED sign (representing the ground truth reference stimulus for eliciting bottom-up/attentional conspicuity) will be significantly more likely to attract priority eye fixations than the control stimuli [Hypothesis 1]. In addition – consistent with previous demonstrations that fluorescent colored targets do not elicit bottom-up conspicuity – it is predicted that the probability of priority fixations to the fluorescent yellow-green target will not differ from the control stimuli and will have significantly less priority fixations than the ground truth reference [Hypothesis 2]. However, since fluorescent colors have been demonstrated to yield high levels of top-down/search conspicuity, it is predicted that both the ground truth stimulus and the fluorescent yellow-green target will elicit significantly greater numbers of fixations per trial as well as increased total glance times relative to the control stimuli [Hypothesis 3].

# METHOD

## Participants

A total of 24 individuals from undergraduate classes at the University of South Dakota were recruited for participation in this study. Since there was sufficient statistical power in the N=10 pilot study to detect attentional conspicuity for the flashing LED sign, 24 participants should be more than adequate to ensure sufficient statistical sensitivity for detecting attentional conspicuity for the flashing LED and the experimental fluorescent sign (if present). All participants were free of self-reported visual problems.

## Experimental Stimuli

The six different stimuli presented to the participants were the same as described in the pilot study. Each stimulus was mounted on a 4x4 inch square piece of metal with either retroreflective red, yellow, orange, green, or fluorescent yellow-green sheeting material affixed to it. The sixth stimulus was a cluster of LED’s used to form a flashing light stimulus. This flashing light stimulus utilized a total of 16 red and yellow LED's hexagonally-packed to form a self-illuminated sign. The flashing LED sign subtended 0.3 degrees of visual angle at the 26 ft viewing distance. The five other 4x4 inch stimuli (red, yellow, orange, green, and fluorescent yellow-green) subtended 0.7 degrees of visual angle at the same viewing distance. The flashing LED sign was temporally modulated at 4 Hz with an equal on-to-off duty cycle. The space-averaged luminance of this display was 1500 cd/m$^2$. Table 2 shows the luminance and color chromaticity coordinates for each of the stimuli. These measurements were performed using a Photo Research Model PR-650 spectroradiometer.

Stimulus Sign Photometric Properties

| Color | Luminance (cd/m$^2$) | CIE 1931 Chromaticity x | CIE 1931 Chromaticity y | |
|---|---|---|---|---|
| Red | 9.88 | 0.472 | 0.320 | |
| Green | 8.47 | 0.221 | 0.368 | |
| Yellow | 28.33 | 0.448 | 0.445 | |
| Orange | 18.97 | 0.484 | 0.373 | |
| Fluorescent Yellow-Green | 58.13 | 0.382 | 0.540 | |
| Gray (Background) | 31.26 | 0.321 | 0.355 | |
| Fluorian-99 (REF white) | 67.43 | 0.322 | 0.353 | CCT=6000 °K |

**Table 2.** Stimulus luminance and chromaticity coordinates.

Each stimulus was magnetically affixed to a gray background scene (see Table 2 for luminance and chromaticity values). Each stimulus was presented at one of 8 predetermined locations surrounding the central fixation cross as depicted in Figure 14.

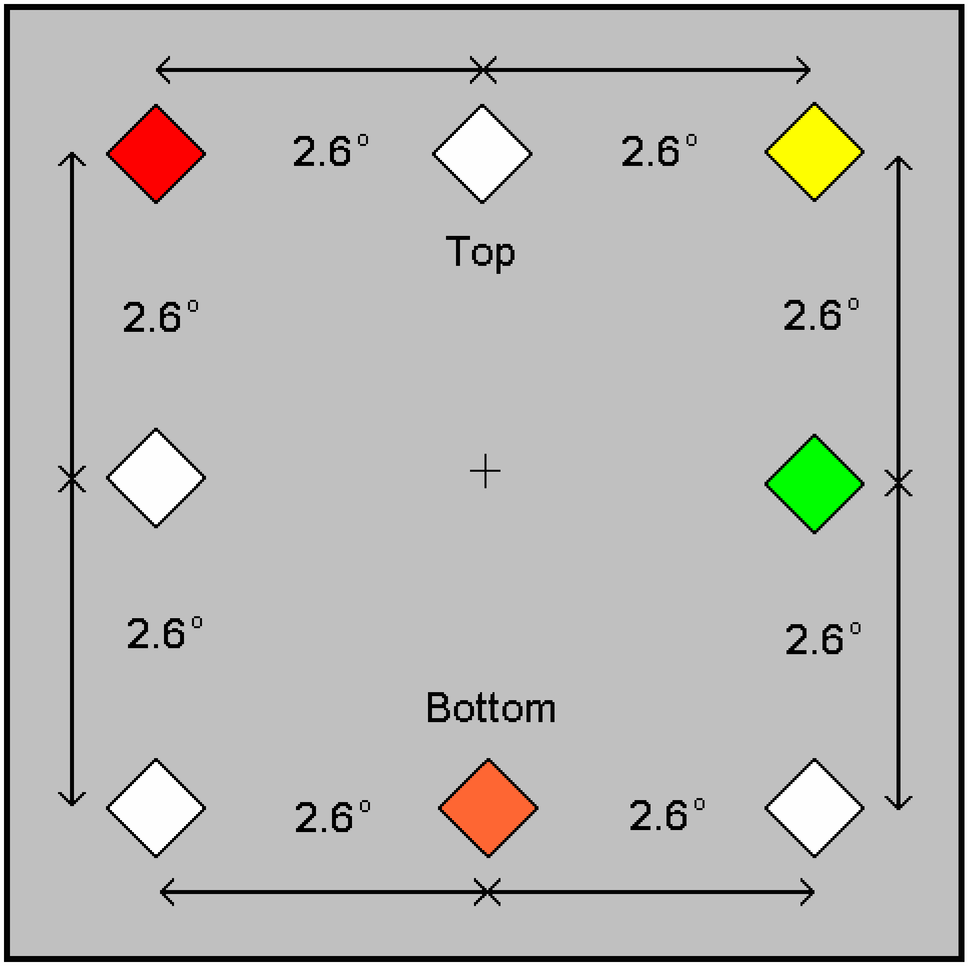


**Figure 14.** The geometric configuration for the possible locations of each stimulus. Separation distances are specified in degrees of visual angle.

## Experimental Apparatus

The same ASL Model 501 head mounted eye-tracking device used in the pilot study was used in the proposed experiment. This device has a minimum absolute accuracy of one degree with relative precision of approximately 0.1 degrees. Figure 14 shows the angular separation of the stimuli relative to the observer at the 26 ft viewing distance. The minimum stimulus separation angle was 2.6 degrees. Given this wide degree of separation between the possible locations of the stimuli, the Model 501 eye tracker enabled the experimenter to reliably distinguish which stimulus target was being fixated at any given time during the experimental protocol.

The experiment was conducted in a vision alley that provided complete isolation from the exterior world and utilized special $D_{65}$ illumination designed to replicate the color spectrum of sunlight at noon. These light bulbs were used to illuminate the stimuli previously described. An electrochromic window was used to control the exposure duration of the stimulus signs. This special window was mounted six feet in front of the stimuli and acted like the shutter on a camera. When the electrochromic window is idle (in the "closed" position) it appeared opaque and virtually impossible to see behind. But, when an electric current is passed through it, the window becomes transparent and the stimuli can be readily observed (see Figures 15 & 16).

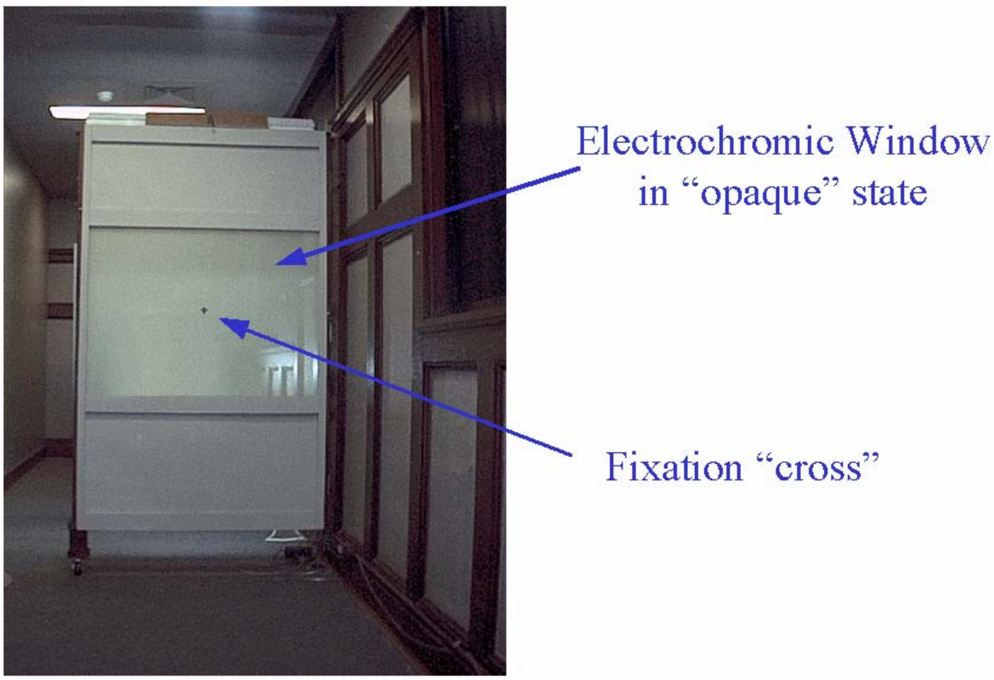


**Figure 15.** Photograph of the electrochromic window in the opaque position. Notice how it is impossible to see the stimuli mounted behind the window.[2]

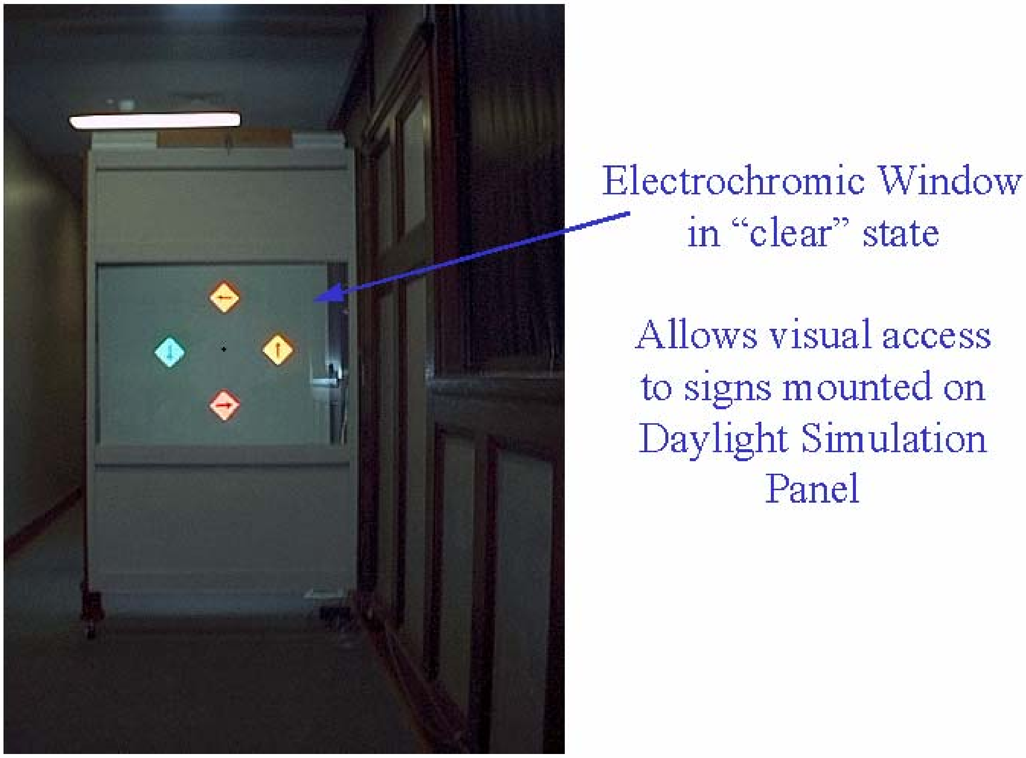


**Figure 16.** Photograph of the electrochromic window in the clear position. Notice how the stimuli are now clearly visible. The arrows seen on the stimuli in this figure will not be used in this experiment.[2]

It should be noted that the distance of the stimulus signs to the electrochromic window was six feet, while the distance from the window to the participant was 20 ft. The total distance of approximately 26 ft from the observer to the stimuli was designated so the stimuli would be at optical infinity; thus minimizing the need for ocular accommodation when the window opened (see Figure 17).

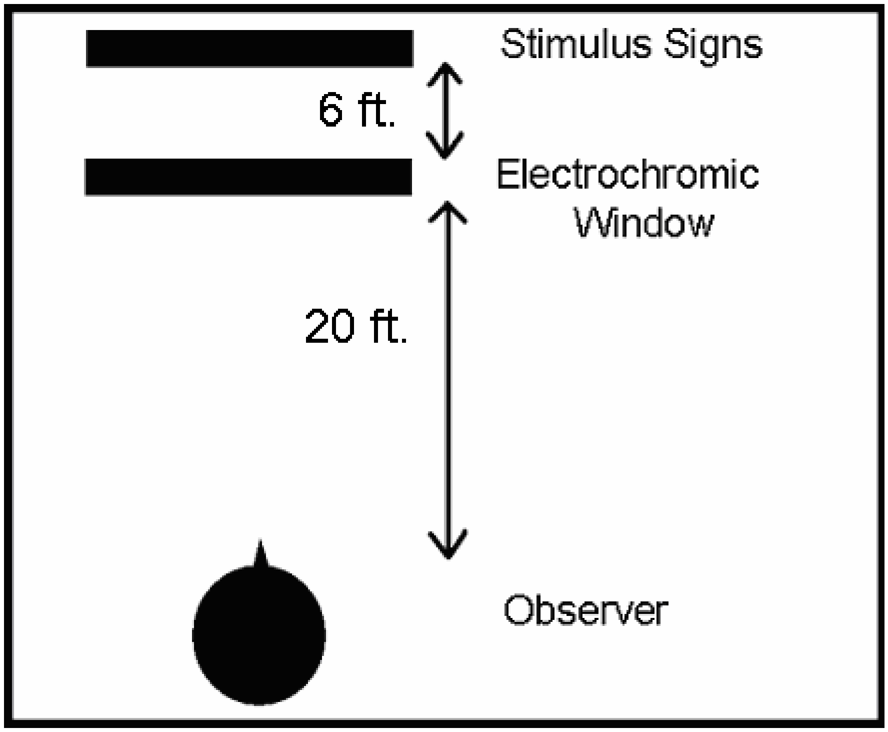


**Figure 17.** Drawing representing the distances and setup used to conduct the experiment.[3]

**Procedure**

Previous permission to conduct this experiment was approved through the Institutional Review Board (IRB) of the University of South Dakota. In compliance with the IRB, each participant signed a consent form notifying them of their rights as a subject before the experiment began. Once the consent form was signed, the eye-tracking device was situated on the participant's head and calibrated. The participant was then instructed to fixate on the small black cross in the middle of the electrochromic window (see the previous Figure 15). Since the cross was lined up with the middle of the stimulus board, this ensured the participants were fixated in the center of the stimuli so as not to produce any unwanted bias with their eyes. This also ensured consistency among each participant and each trial.

There was a total of 18 stimulus trials presented in this experiment. As implied above, a trial began only when the participant had maintained steady gaze upon the central fixation cross. Each trial consisted of a 5 sec exposure of 4 stimulus signs. Sixteen of the trials were designated as control trials in which the 4 non-fluorescent colored signs (retroreflective red, green, yellow, and orange) were presented in predetermined randomized positions. Trials 9 and 18 were designated as experimental trials in which the non-fluorescent yellow sign were replaced with either the fluorescent yellow-green or the flashing LED targets. The order of presentation, as well as the relative mounting position of the experimental stimuli, was equally distributed across participants to control for order and location effects. In summary: On any given trial only four stimuli were displayed to the participant. Once the participant was looking at the fixation cross and ready to begin, the experimenter activated the electrochromic window to open for five seconds. After five seconds the window closed and the experimenter rearranged the position of the sign stimuli and a new trial commenced. When the critical trials 9 or 18 were to be displayed, the experimenter replaced the non-fluorescent yellow stimulus with either the fluorescent yellow-green stimulus or the flashing LED stimulus.

The participant's task was quite simple. They were instructed to inspect the abstract pattern of signs presented on each trial while their eye movements were recorded. In addition, they were instructed that the experimenter would ask them "some questions" about the stimuli at the end of the experiment. The experimenter provided no additional information about the nature of their task in an attempt to minimize systematic top-down biases in the search behavior of the participants.

Since there was no central task for the participants other than to view the stimuli presented to them (since they were to be asked about them later), the only data being collected was the eye movement data. The output video of the eye tracker contained images from the head-mounted scene camera containing a graphical overlay designating the point of gaze. The stream of video images was updated at a rate of 30 frames per second. The eye marker video was captured using a standard VCR. The resultant video tapes were subsequently converted to digital format (30 FPS) using an ATI All-in-Wonder card and stored on computer disk. The digitized eye-tracking video was analyzed on a frame-by-frame basis to quantify the eye gaze behavior exhibited on each stimulus trial.

## RESULTS

An off-line analysis of the video records was performed to reconstruct the time series depicting eye gaze behavior on each trial. Since the video data was digitized at 30 frames per sec, the minimum time unit of analysis was approximately 33 msec (i.e., 1/30 sec). Thus, for each trial, the following information was available: (1) the order of eye gaze fixation for each stimulus presented, (2) the total glance time per stimulus sign and (3) the total number of fixations elicited per stimulus.

Four separate within subjects repeated-measures ANOVAs were calculated using combinations of the 6 different stimuli (4 non-fluorescent control stimuli, 1 fluorescent yellow-green stimulus, and 1 flashing LED sign). The separate repeated-measures ANOVAs were as follows: (1) Controls vs. Themselves, (2) Controls vs. Fluorescent yellow-green, (3) Controls vs. Flashing LED, (4) Fluorescent yellow-green vs. Flashing LED. Each of the 4 repeated-measures ANOVAs was performed for the previously mentioned informational categories: (1) the order of eye gaze fixation for each stimulus presented, (2) the total glance time per stimulus sign and (3) the total number of fixations elicited per stimulus. This resulted in 12 separate repeated-measures ANOVAs. It should be noted that none of the control stimuli from any of the repeated-measures ANOVAs differed from one another and thus, were collapsed into a single stimulus category when calculated against any other stimulus. This resulted in only a single non-fluorescent control stimulus category for ANOVA 2 (Controls vs. Fluorescent yellow-green) and ANOVA 3 (Controls vs. Flashing LED).

The average order of eye fixation number marking the first glance to each stimulus category (i.e. priority fixation) was used to test Hypotheses 1 and 2. As predicted in Hypothesis 1, the flashing LED sign representing the ground truth reference stimulus was significantly more likely to attract priority eye fixations than the non-fluorescent control stimuli [$F(1,23)=23.87$, $p<0.001$]. As anticipated, the likelihood of eliciting first fixation was equivalent across the four non-fluorescent control stimuli [$F(3,69)=1.25$, *N.S.*].

Inconsistent with Hypothesis 2, the fluorescent yellow-green sign was more likely to attract priority fixation than the non-fluorescent control stimuli [$F(1,23)=66.92$, $p<0.001$]. There was however, no significant difference in the priority fixation index when comparing the fluorescent yellow-green sign with the flashing LED stimulus [$F(1,23)=0.10$, *N.S.*]. For the above mentioned results refer to Table 3.

## Mean Priority Glance Order

| Subject | Red | Green | Yellow | Orange | FL | LED |
|---|---|---|---|---|---|---|
| 1 | 3.222 | 3.353 | 2.938 | 3.278 | 2.0 | 1.0 |
| 2 | 2.765 | 3.056 | 3.188 | 3.111 | 2.0 | 1.0 |
| 3 | 2.706 | 2.375 | 2.375 | 2.438 | 1.0 | 1.0 |
| 4 | 2.647 | 2.235 | 2.857 | 2.412 | 3.0 | 1.0 |
| 5 | 3.000 | 2.294 | 2.643 | 2.733 | 1.0 | 1.0 |
| 6 | 2.667 | 2.765 | 2.750 | 1.824 | 1.0 | 4.0 |
| 7 | 2.882 | 3.353 | 1.733 | 2.875 | 1.0 | 1.0 |
| 8 | 2.938 | 2.118 | 3.133 | 2.667 | 1.0 | 1.0 |
| 9 | 3.111 | 2.438 | 2.500 | 3.529 | 2.0 | 1.0 |
| 10 | 2.722 | 2.667 | 2.875 | 2.778 | 1.0 | 1.0 |
| 11 | 3.611 | 3.667 | 1.688 | 2.722 | 1.0 | 1.0 |
| 12 | 3.438 | 2.813 | 1.667 | 2.824 | 1.0 | 1.0 |
| 13 | 2.611 | 2.667 | 2.438 | 3.000 | 1.0 | 2.0 |
| 14 | 2.588 | 2.706 | 2.857 | 2.412 | 1.0 | 1.0 |
| 15 | 2.765 | 3.222 | 2.813 | 2.833 | 2.0 | 1.0 |
| 16 | 2.556 | 3.294 | 2.938 | 2.778 | 1.0 | 1.0 |
| 17 | 1.929 | 3.077 | 3.667 | 2.667 | 2.0 | 1.0 |
| 18 | 2.556 | 2.588 | 2.688 | 3.111 | 1.0 | 4.0 |
| 19 | 4.222 | 2.056 | 2.875 | 3.444 | 2.0 | 1.0 |
| 20 | 2.647 | 2.250 | 2.333 | 3.000 | 4.0 | 4.0 |
| 21 | 3.125 | 2.867 | 2.563 | 3.000 | 1.0 | 1.0 |
| 22 | 2.222 | 2.611 | 2.688 | 3.000 | 1.0 | 4.0 |
| 23 | 3.118 | 3.267 | 2.313 | 2.118 | 1.0 | 1.0 |
| 24 | 2.944 | 2.500 | 2.563 | 3.056 | 1.0 | 1.0 |
| | | | | | | |
| **Average** | **2.875** | **2.760** | **2.628** | **2.817** | **1.458** | **1.542** |

**Table 3.** The order of first eye gaze fixation (i.e. priority glance) averaged across all trials for each participant.

In order to test Hypothesis 3, both the total number of fixations to each stimulus and the total glance time elicited by each stimulus category were analyzed in separate repeated-measures ANOVAs. Again, the same separate repeated-measures ANOVAs were used: (1) Controls vs. Themselves, (2) Controls vs. Fluorescent yellow-green, (3) Controls vs. Flashing LED, (4) Fluorescent yellow-green vs. Flashing LED. Also, as previously noted, only a single non-fluorescent control stimulus category was used for ANOVA 2 (Controls vs. Fluorescent yellow-green) and ANOVA 3 (Controls vs. Flashing LED).

From Hypothesis 3, it was predicted that the fluorescent yellow-green stimulus and the flashing LED sign would attract significantly greater numbers of fixations and longer total glance times than the non-fluorescent control stimuli. The fluorescent yellow-green sign was found to have a longer total glance time than the control stimuli [$F(1,23)=57.61$, $p<0.001$]. The flashing LED sign, as well, was found to elicit longer total glance times than the non-fluorescent control stimuli [$F(1,23)=38.22$, $p<0.001$]. None of the control stimuli were found to be different from one another with respect to total glance times [$F(3,69)=1.13$, *N.S.*]. The flashing LED was shown to elicit a longer total glance time than the fluorescent yellow-green stimulus [$F(1,23)=5.46$, $p<0.05$]. This finding is vital to our understanding of fluorescent yellow-green signing material salience, and will be explained in greater detail later in the paper. The aforementioned data is shown in Table 4.

**Total Glance Time**
(# of video frames)

| Subject | Red | Green | Yellow | Orange | FL | LED |
|---|---|---|---|---|---|---|
| 1 | 24.556 | 28.706 | 33.125 | 28.667 | 65.0 | 43.0 |
| 2 | 24.824 | 25.556 | 30.625 | 27.111 | 60.0 | 131.0 |
| 3 | 18.412 | 15.188 | 18.750 | 24.938 | 59.0 | 99.0 |
| 4 | 25.588 | 29.412 | 27.357 | 25.059 | 70.0 | 69.0 |
| 5 | 28.750 | 29.412 | 35.429 | 34.400 | 60.0 | 104.0 |
| 6 | 27.500 | 30.353 | 27.688 | 37.471 | 46.0 | 50.0 |
| 7 | 24.353 | 28.294 | 32.267 | 25.125 | 91.0 | 111.0 |
| 8 | 22.188 | 21.765 | 20.667 | 22.278 | 36.0 | 64.0 |
| 9 | 30.111 | 27.688 | 28.563 | 30.882 | 29.0 | 58.0 |
| 10 | 32.500 | 28.111 | 23.875 | 27.611 | 41.0 | 81.0 |
| 11 | 39.000 | 42.333 | 26.188 | 22.833 | 42.0 | 17.0 |
| 12 | 24.438 | 23.438 | 20.000 | 20.000 | 91.0 | 88.0 |
| 13 | 28.500 | 26.667 | 32.938 | 28.889 | 59.0 | 52.0 |
| 14 | 21.235 | 20.412 | 33.857 | 39.176 | 38.0 | 32.0 |
| 15 | 32.000 | 32.000 | 32.000 | 25.167 | 35.0 | 42.0 |
| 16 | 22.056 | 23.824 | 27.563 | 25.500 | 58.0 | 66.0 |
| 17 | 26.071 | 21.385 | 17.077 | 22.400 | 38.0 | 52.0 |
| 18 | 23.000 | 21.706 | 26.500 | 15.444 | 77.0 | 65.0 |
| 19 | 22.833 | 29.167 | 32.313 | 23.444 | 78.0 | 116.0 |
| 20 | 33.176 | 26.438 | 33.467 | 30.944 | 72.0 | 55.0 |
| 21 | 27.125 | 27.000 | 37.563 | 23.063 | 48.0 | 93.0 |
| 22 | 29.944 | 29.222 | 31.688 | 29.667 | 53.0 | 26.0 |
| 23 | 28.588 | 26.467 | 33.375 | 28.412 | 73.0 | 125.0 |
| 24 | 27.667 | 31.389 | 26.375 | 27.722 | 40.0 | 32.0 |
| | | | | | | |
| **Average** | **26.851** | **26.914** | **28.719** | **26.925** | **56.625** | **69.625** |

**Table 4.** The total glance time averaged across all trials for each participant.

It is apparent from Table 4 that the average total glance time collapsed across all of the control stimuli is 27.352 video frames. As stated previously, since the video data was digitized at 30 frames per sec, the minimum time unit of analysis was approximately 33 msec (i.e., 1/30 sec). It can therefore be concluded that the average total glance time elicited by each of the non-fluorescent control stimuli was approximately 912 msec. It is also shown in Table 4 that the average total glance time elicited by the fluorescent yellow-green stimulus was approximately 1888 msec (56.625 frames). The flashing LED was shown to elicit an average total glance time of 69.625 video frames. That is, each participant spent an average of 2321 msec looking at the flashing LED stimulus.

To provide further support for Hypothesis 3, the total number of eye fixations to each stimulus was also analyzed. The same within subjects repeated-measures ANOVA design used to determine the priority eye fixations and the total glance time was again used to determine the total number of eye gaze fixations. Also, as in the previous two analyses, none of the control stimuli were found to be different from one another with respect to the total number of eye fixations [$F(3,69)=1.53$, *N.S.*]. Since no significant difference was shown between any of the control trials for the average number of eye fixations made to each non-fluorescent control stimuli, Table 5 shows the average number of eye fixations made to each control stimuli per trial was approximately 1.872.

## Total Number of Eye Fixations

| Subject | Red | Green | Yellow | Orange | FL | LED |
|---|---|---|---|---|---|---|
| 1 | 2.667 | 2.353 | 2.688 | 2.500 | 5.0 | 2.0 |
| 2 | 1.706 | 1.889 | 1.875 | 1.833 | 3.0 | 2.0 |
| 3 | 1.353 | 1.250 | 1.250 | 1.500 | 4.0 | 2.0 |
| 4 | 1.882 | 2.059 | 1.786 | 2.235 | 2.0 | 3.0 |
| 5 | 1.563 | 1.824 | 2.071 | 1.800 | 3.0 | 2.0 |
| 6 | 1.944 | 1.706 | 1.938 | 2.059 | 2.0 | 1.0 |
| 7 | 1.529 | 1.765 | 1.867 | 1.750 | 4.0 | 2.0 |
| 8 | 1.688 | 1.941 | 1.333 | 1.833 | 3.0 | 2.0 |
| 9 | 1.722 | 2.188 | 1.938 | 1.882 | 2.0 | 2.0 |
| 10 | 1.889 | 1.944 | 1.688 | 1.889 | 2.0 | 2.0 |
| 11 | 1.500 | 1.611 | 1.500 | 1.500 | 2.0 | 1.0 |
| 12 | 1.563 | 1.688 | 1.533 | 1.412 | 3.0 | 2.0 |
| 13 | 1.889 | 2.056 | 1.875 | 2.111 | 2.0 | 3.0 |
| 14 | 1.235 | 1.294 | 1.357 | 1.882 | 2.0 | 3.0 |
| 15 | 1.588 | 1.611 | 1.438 | 1.611 | 3.0 | 2.0 |
| 16 | 2.278 | 2.118 | 2.500 | 2.000 | 3.0 | 2.0 |
| 17 | 2.000 | 1.615 | 1.385 | 1.667 | 3.0 | 3.0 |
| 18 | 2.333 | 2.471 | 2.313 | 2.167 | 5.0 | 3.0 |
| 19 | 1.556 | 2.278 | 2.063 | 1.722 | 5.0 | 2.0 |
| 20 | 2.412 | 2.375 | 2.533 | 2.222 | 3.0 | 2.0 |
| 21 | 1.625 | 1.867 | 2.000 | 1.875 | 4.0 | 2.0 |
| 22 | 2.111 | 2.222 | 2.188 | 2.056 | 2.0 | 1.0 |
| 23 | 1.706 | 2.000 | 1.813 | 1.941 | 4.0 | 3.0 |
| 24 | 1.944 | 2.000 | 1.563 | 1.944 | 4.0 | 2.0 |
| | | | | | | |
| **Average** | **1.820** | **1.922** | **1.854** | **1.891** | **3.125** | **2.125** |

**Table 5.** The total number of eye fixations averaged across all trials for each participant.

Also from Table 5, the fluorescent yellow-green stimulus was shown to elicit significantly more eye fixations in comparison to the non-fluorescent control stimuli [$F(1,23)=37.55$, $p<0.001$]. This equates to approximately 3.125 eye fixations elicited by the fluorescent yellow-green stimulus. Table 5 also indicates the flashing LED sign was not significantly different from the control stimuli with respect to total number of eye fixations (at the $p<.05$ level) [$F(1,23)=3.36$, N.S. (marginal significance $p<0.08$)]. This equates to approximately 2.125 eye fixations elicited by the flashing LED sign. It was found, however, that there were significantly more eye fixations elicited by the fluorescent yellow-green stimulus when compared to the flashing LED sign [$F(1,23)=19.71$, $p<0.001$]. The two previous findings are important for our understanding of fluorescent yellow-green signing material salience and abrupt onset capture of attention. These important findings will be described in greater detail in the following section.

## DISCUSSION

The current literature regarding the use of modern fluorescent photopigments for highway signs has established a very compelling case regarding their enhanced visibility. Fluorescent colored materials as compared to their non-fluorescent counterparts have been shown to be more conspicuous, provide better legibility at further distances, and even involuntarily capture an observer’s attention. Many researchers and traffic engineers have suggested that the use of fluorescent photopigments in traffic signs should reliably capture the attention of unsuspecting drivers. However, Schieber, et al. (2002) challenged this claim based upon a lack of direct evidence. Indeed, when these investigators used an inattention search paradigm designed to distinguish bottom-up versus top-down mediators of enhanced visibility, they failed to find evidence supporting the claim that fluorescent colored materials foster attentional conspicuity (i.e., bottom-up attraction of attention).

Unfortunately, the Schieber, et al. (2002) findings did not definitively rule out the possibility that fluorescent colors may attract attention involuntarily via bottom-up mechanisms. An alternative explanation was proposed that participants may have developed an active suppression of color information during the 32 trials preceding the critical test of the unexpected fluorescent colored stimulus. In order to bypass the potential role of such active suppression of color information, the current investigation abandoned the traditional visual search paradigm in favor of a more direct approach based upon the measurement of eye movement behavior. Results from the present study strongly suggest that Schieber, et al.'s (2002) conclusions discounting the attentional conspicuity of fluorescent colors may have been premature.

Experimental Hypotheses 1 and 2 predicted that initial eye gaze fixation to the colored stimulus array should be characterized by (1) greater probability of early fixations to the flashing LED target representing the ground truth bottom-up stimulus with (2) no difference in the probabilities of capturing early fixations between the fluorescent versus the non-fluorescent colored controls. Both of these hypotheses follow from the claim that fluorescent colored materials do not possess significant attentional conspicuity. The later of these hypotheses failed to be supported by the eye movement data collected in this experiment. Hence, the concern regarding the participants suppressing color information in the visual search paradigm has been validated. It appears that during the visual search experiment when the participants were trying to locate the up-arrow target, they had a tendency to suppress (irrelevant) color information during the initial trials. This was confirmed with the use of the eye-tracking device since the only task given to the participants was to "observe the stimuli presented." Given experimental conditions in which active suppression of irrelevant color information was not allowed to develop, the eye-tracking data provided clear evidence that fluorescent colored stimuli attract attention via bottom-up mechanisms.

Analyses of the eye movement data also provided insights regarding top-down mechanisms of visual attention. These analyses were based upon the total number of eye fixations as well as the total fixation times accumulated across the three experimental conditions of interest; namely, the flashing LED, fluorescent colored target, and the non-fluorescent colored control stimuli. At first glance it seemed as though there was a discrepancy when analyzing the total glance time and total number of eye fixations between the fluorescent yellow-green stimulus and the flashing LED sign. However, on closer inspection this "discrepancy" is just what one might expect to observe. Despite the fact that the fluorescent yellow-green stimulus and flashing LED sign proved to be more salient and have longer total glance times than the non-fluorescent control stimuli; there was also a significant difference in the total glance times between both the fluorescent and flashing LED stimuli. It is shown that the average total glance time participants spent looking at the fluorescent yellow-green stimulus was significantly less than that of the flashing LED sign. This finding does not seem out of the ordinary until comparing the fluorescent yellow-green and flashing LED stimuli with respect to the total number of eye fixations to each stimulus. The average total number of eye fixations made by each participant to the fluorescent yellow-green stimulus was greater than that for the flashing

LED sign. This was unusual because it was also found that there is no significant difference between the flashing LED and the non-fluorescent control stimuli in regards to the total number of eye fixations participants made to each stimulus.

Why is it that participants spend a greater portion to time looking at the flashing LED than looking at the fluorescent yellow-green stimulus, yet, make more eye fixations per trial to the fluorescent yellow-green stimulus than to the flashing LED sign? The answer to this is quite simple. Since participants spend a greater amount of time looking at the flashing LED, they in essence could not make as many eye fixations to it. This would explain why on average participants spent a greater portion of time looking at the flashing LED but only made a couple of glances to it. The opposite goes for the fluorescent yellow-green stimulus. Since participants did not spend as long looking at the fluorescent yellow-green stimulus, they had more time to make multiple glances toward it. It can also be speculated that the flashing LED sign has a much greater salient signature than the fluorescent yellow-green stimulus, and because of this, participants spend a great deal more time per fixation focused on the flashing LED. This might explain the significant difference found in total glance times between the flashing LED and the fluorescent yellow-green stimulus. It also suggests that the fluorescent yellow-green sign possesses an enhanced salient signature making it conspicuous enough to warrant a great deal more eye gaze fixations than any other stimulus.

Research on the mechanisms mediating the enhanced visibility of fluorescent colored materials has appeared to have come full circle in the Heimstra Human Factors Laboratories. That is, initial studies based upon enhanced visual search techniques indicated that fluorescent colors failed to attract attention in a bottom-up fashion.

However, follow-up investigations (including the current study) using eye movement data have now revealed strong evidence that fluorescent colors can attract visual attention via automatic, involuntary, bottom-up processes. The circular nature of this progression will be remedied only when visual search techniques can be developed that possess adequate sensitivity for the discrimination of bottom-up versus top-down attentional influences. The search for such techniques continues both inside the Heimstra Labs and within the research community beyond the confines of our research group.

The major conclusion to be drawn from the current investigation is that fluorescent colored materials do indeed have the potential to attract visual attention using bottom-up mechanisms. An extensive and exhaustive review of the research literature reveals that our findings represent the first direct evidence supporting this widely held but heretofore undemonstrated assumption. Additional work is necessary to advance our understanding of roadway safety.

# FOOTNOTES

[1]Dr. Frank Schieber provided the graph of the probability of eliciting participants' first eye fixation as a function of stimulus type (2003).

[2]Dr. Frank Schieber provided the pictures showing the electrochromic window in both the opaque and clear positions (2002).

[3]Dr. Frank Schieber provided the drawing showing the visual setup used to conduct the experiment (2002).

## REFERENCES

Burns, D. M., & Donahue, T. J. (2001, January). *Comparison of field measurements of the brightness and color of fluorescent yellow and fluorescent yellow green retroreflective signs.* Paper presented at the 80$^{th}$ Annual Meeting of the Transportation Research Board, Washington, D.C.

Burns, D. M., & Johnson, N. L. (1995, September). *The correlation of measured spectral radiance of fluorescent and non-fluorescent materials to perceived conspicuity under natural lightning.* Paper Presented at the AIC Interim Meeting on Colorimetry, Berlin.

Burns, D. M., Johnson, N. L., & Pavelka, L. A. (1995). Colorimetry of durable fluorescent retroreflective materials. *Color Research and Application, 20(2),* 93 106.

Burns, D. M., & Pavelka, L. A. (1993). *Fluorescent retroreflective materials for improved roadway safety.* Paper presented at the 12$^{th}$ World Congress, International Road Federation, Madrid.

Burns, D. M., & Pavelka, L. A. (1995). Visibility of durable fluorescent materials for signing applications. *Color Research and Application*, *20(2)*, 108-116.

Dutt, N., Hummer, J., & Clark, K. (1996, December). *User preferences of fluorescent strong yellow-green pedestrian crossing sign.* Paper presented at the 76$^{th}$ Annual Meeting of the Transportation Research Board, Washington, DC.

Dutt, N., Hummer, J., Clark, K., & Blakely, S. (1995, January). *Controlled environment evaluation of fluorescent strong yellow-green pedestrian crossing sign prototypes.* Paper presented at the 75th Annual Meeting of the Transportation Research Board, Washington, DC.

Eccles, K. A., & Hummer, J. E. (2001, January). *Safety Effects of fluorescent yellow warning signs at hazardous sites.* Paper presented at the 80th Annual Meeting of the Transportation Research Board, Washington, DC.

Egeth, H., & Yantis, S. (1997). Visual attention: Control, representation, and time course. *Annu. Rev. Psychol, 48,* 269-297.

Franconeri, S., Hollingworth, A., & Simons, D. (2005). Do new objects capture attention? *Psychological Science, 16(4),* 275-281.

Franconeri, S., & Simons, D. (2003). Moving and looming stimuli capture attention. *Perception & Psychophysics, 65(7),* 999-1010.

Green. P. (2002). Where do drivers look while driving (and for how long)? In Dewar, R. E. and Olson, P.L. (Eds.), *Human Factors in Traffic Safety.* Tucson, AZ: Lawers and Judges Publishing (pp. 77-110).

Hawkins, G. H., Carlson, P. J., & Elmquist, M. (1999, January). *Evaluation of weathering data for fluorescent orange sheeting.* Paper presented at the 78th Annual Meeting of the Transportation Research Board, Washington, DC.

Hummer & Scheffler (1999, January). *Driver performance comparison of fluorescent orange to standard orange work zone traffic signs*. Paper presented at the 78th Annual Meeting of the Transportation Research Board, Washington, DC.

Jenkins & Cole (1986). Daytime conspicuity of road traffic control devices. *Transportation Research Record 1093*, 74-80.

Jenssen, G. D. (1995). *Visibility of fluorescent retroreflective traffic control devices part 0: Background study* (Report No. STF63 A95013). Norway: SINTEF Transport Engineering.

Jenssen, G. D., et al. (1996). *Visual Performance of Fluorescent retroreflective traffic control devices part 1: Human factors visibility study* (Report No. STF22 A96606). Norway: SINTEF Transport Engineering.

Kramer, et al. (2001). Influence of single and multiple onset distracters on visual search for singleton targets. *Perception & Psychophysics, 63(6)*, 952-968.

Mack, A., & Rock, I. (1998). Inattentional blindness. Psyche, 5(3). Retrieved April 23, 2005, from http://psyche.cs.monash.edu.au/v5/psyche-5-03-mack.html

Ryer, A. (1998). Light measurement handbook. Retrieved March 17, 2005, from http://intl-light.com

Sayer J., & Mefford M. (2000). *The effect of color contrast on daytime and nighttime conspicuity of roadworker vests* (Report No. UMTRI-2000-35). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Schieber, F., Larsen, J., Jurgensen, J., Werner, K. & Eich, G. (2001). Fluorescent colored highway signs don't 'grab' attention; They 'guide' it. *Proceedings of the Human Factors and Ergonomic Society.* Santa Monica, CA.

Schieber, F. (2002). *Searching for fluorescent colored highway signs: Bottom-up versus top down mechanisms.* Paper presented at the Transportation Research Board's 16th Biennial Meeting on Visibility, Iowa City, IA.

Schnell et al. (2001a, January). *Driver looking behavior in school zones with fluorescent yellow green and normal yellow signs.* Paper presented at the 80th Annual Meeting of the Transportation Research Board, Washington, D.C.

Schnell et al. (2001b, January). *Legibility distances of fluorescent traffic signs and their normal color counterparts.* Paper presented at the 80th Annual Meeting of the Transportation Research Board, Washington, D.C.

Solomon, S., & King, J. (1997). Fire truck visibility. *Ergonomics in Design, 5(2),* 4-10.

Theeuwes, J. (2004). Top-down search strategies cannot override attentional capture. *Psychonomic Bulletin & Review, 11(1),* 65-70.

Treisman, A. (1986). *Features and objects in visual processing.* Scientific American, 254, No. 11, 114-125.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance, 10(5),* 601-621.

Zwahlen, H. T., & Vel, U. D. (1992, January). *Conspicuity in terms of peripheral visual detection and recognition of fluorescent color targets vs. non-fluorescent color targets against different backgrounds during daytime.* Paper Presented at the 71st Annual Meeting Transportation Research Board, Washington, DC.

Zwahlen, H.T., & Schnell, T. (1997, January). *Visual detection and recognition of fluorescent colored targets versus non-fluorescent color targets as a function of peripheral viewing angle and target size.* Paper Presented at the 76th Annual Meeting Transportation Research Board, Washington, DC.