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Applying visual attention theory to transportation safety research and design: Evaluation of alternative automobile rear lighting systems

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ABSTRACT

This field experiment takes a novel approach in applying methodologies and theories of visual search to the subject of conspicuity in automobile rear lighting. Traditional rear lighting research has not used the visual search paradigm in experimental design. It is our claim that the visual search design uniquely uncovers visual attention processes operating when drivers search the visual field that current designs fail to capture. This experiment is a validation and extension of previous simulator research on this same topic and demonstrates that detection of red automobile brake lamps will be improved if tail lamps are another color (in this test, amber) rather than the currently mandated red. Results indicate that when drivers miss brake lamp onset in low ambient light, RT and error are reduced in detecting the presence and absence of red brake lamps with multiple lead vehicles when tail lamps are not red compared to current rear lighting which mandates red tail lamps. This performance improvement is attributed to efficient visual processing that automatically segregates tail (amber) and brake (red) lamp colors into distractors and targets respectively.

1. Introduction

The brake signal is considered a primary safety signal in automotive transportation. Many decades of research have been devoted to improving the conspicuity of the brake signal in an effort to reduce vehicular accidents (Lee et al., 2002). In the U.S., the agency under the United States Department of Transportation (USDOT) tasked with improving signaling on automobiles is the National Highway Transportation and Safety Administration (NHTSA). The purpose of current automotive rear lighting mandated in much of the world by the USDOT and the United Nations Economic Commission for Europe (UNECE) as summarized by the Federal Motor Vehicle Safety Standards (FMVSS) 108 is to enhance the "conspicuity of motor vehicles on the public roads so that their presence is perceived and their signals understood, both in daylight and in darkness or other conditions of reduced visibility" (USDOT, 2011, §571.108, S2. *Purpose*, UNECE, 2006).

Because the brake lamp and tail (rear presence) lamp are required to be the same color, the focus of most of the research designed to make the brake lamp more conspicuous has been to disambiguate the brake signal from the tail (presence) lamps by adding additional characteristics to the brake lamp such as greater luminance and on most vehicles a novel location with the Center High Mounted Stop Lamp (CHMSL). A few researchers have taken a different approach to make the brake lamp more conspicuous and investigated the effectiveness of changing the color of tail lamps on the conspicuity of brake lamps (Allen, 1964; Case et al., 1969; Mortimer, 1968, 1969; Cameron, 1992, 1995). In this approach, the color red is reserved for the brake signal only. The data provide some indication that changing the color of the tail lamp without changing the brake lamp differentiates brake and tail lamps sufficiently to reduce response time (RT) and error in detecting brake lamps and other signals in comparison to the current system. However, studies sponsored by NHTSA examining rear lighting have not experimentally examined changing tail lamp color for at least two reasons (Lee et al., 2002; Wierwille et al., 2003; Llaneras et al., 2010). First, the federal code mandates that tail and brake lamps emit the same hue and overturning this legal requirement is rightfully not taken lightly. However, the origins of this requirement are not based on scientific research, but on a sequence of historical events in which tail lamps were in use and required to be red prior to the invention of the brake lamp (Moore and Rumar, 1999). Second, color coding the signals as a way to increase brake lamp conspicuity has been discarded as a valid hypothesis because previous research like that of Mortimer (1968, 1969) and Cameron

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(1995) lack key statistical analysis and do not have large effect sizes (Lee et al., 2002).

The field experiment described in this paper was designed to demonstrate that the color coding hypothesis may have been discarded prematurely. The experiment proposes to demonstrate that color coding rear lighting signals (by changing the color of tail lamps to amber while leaving the brake lamps red) engages more efficient attention processes in identifying both the presence and absence of red brake lamps than does separating the lamps by luminance. Adopting hypotheses and methodological manipulations from basic visual search theory is the key to this approach. Visual search tasks typically measure participant RT in discrete trials detecting presence and absence of targets amongst differing numbers of distracter stimuli displayed on a computer screen. Visual search data has demonstrated that a key to defining efficient (parallel) and inefficient (serial) search for targets is in manipulating number of distracters (set size). From that research we have also learned that only a few stimulus features (like color differences) are consistently capable of maintaining efficient searches as set size increases and measuring RT to target absence is an important measure of target/distracter discriminability (Wolfe and Horowitz, 2004; Wolfe, 2007).

Recent simulator studies have utilized visual search principles and provided some evidence that color coding of tail and brake lamps markedly improves speed and accuracy in detecting brake lamps (McIntyre, 2008, 2009; McIntyre et al., 2012). The 2012 study had drivers follow either two or eight lead vehicles in a moderate-fidelity driving simulator 15 min nighttime highway drive while indicating detection of lead vehicle brake lamp activations. There is also support that occulomotor behavior is different in these searches, with significantly fewer saccades and longer fixations with color coding. This harmonizes with visual search data that has demonstrated automatic capture or guidance of attention with color coding that can in effect reduce the need for shifting of focused attention by taking advantage of efficient attention processes. It is proposed that the same mechanisms are operating when drivers search for target red brake lamps when distractor tail lamp color is not red.

While terms borrowed from visual search will be used throughout the paper, it is acknowledged that the methods used in this field experiment are only presented as analogous and not identical to visual search experiments for several reasons but use the common vernacular in order to retain the connection to the theoretical research. This field study and the previous ones by McIntyre (2008, 2009) and McIntyre et al. (2012) are meant to show industry researchers the advantages of using principles learned from visual search. These recent studies differ methodologically from previous studies on rear lighting in significant ways because the recent studies were conducted using methods borrowed from the visual search paradigm. Most previous studies have not used set size manipulations, and instead have only used a single lead vehicle to serve as both target and distractor location. This seems inadequate for two reasons. One, it does not represent the difficult attention problem drivers frequently face when driving in traffic, i.e., having to search for braking signals and other potential hazards over multiple vehicles. And two, in the visual search paradigm set size manipulations (in this case using multiple lead vehicles) are viewed as the primary way to differentiate efficient and inefficient search. Additionally, most previous research typically only obtains target present data (and sometimes secondary task data). The visual search paradigm places just as much emphasis on the cognitive resources needed to detect the absence of targets as it does their presence. The introduction of these two methodological manipulations (set size and target absent trials) not only increases the analyzable information by increasing the data set fourfold but also furnishes what has been considered the fundamental manipulation (set size) able to assess visual search attention processes.

The experiment in this paper extends and validates the simulator research indicating that changing the color of the tail lamp allows faster and more accurate detection of the presence and absence of red brake lamps compared to luminance differences. This study was conducted to address ambient and vehicle lamp luminance constraints in McIntyre's previous simulator studies. Driver performance in detecting the presence and absence of brake lamps was compared in three conditions: between the current lighting and two alternative systems employing color differentiation of brake and tail lamps.

1. *Red* – the current system with red brake and red tail lamps.
2. *Amber DOT* – the brake lamp remains red and only the lens of the red tail lamp is replaced with an amber lens.
3. *Amber Matched* – same as Amber DOT with the exception that the luminance of the lamp is reduced to match current red tail lamps.

The first two conditions are a test of the tail lamp color change as might happen in practical implementation of the idea while the third is to control for a luminance/brightness confound because the single manipulation of changing the lens color of the tail lamp to amber also increases luminance and the lamp appears brighter.

We hypothesize that with a single vehicle, RT and error for amber and red tail lamps will not differ much. The increase in RT and error with set size will be negligible with amber tail lamps and larger with red tail lamps (due to inefficient serial processing), leading to an interaction of set size and tail lamp color. The increase in RT and error with set size for red tail lamps will be greater when the brake signal is absent than present; because more targets must be serially processed when the brake signal is absent.

With a single vehicle, RT and error for brake present vs. absent should not differ much, since only one vehicle needs to be searched in either condition. When multiple vehicles are searched and tail lamps are amber, brake absent responses may be slower than present responses with amber tail lamps because the cost of missing a safety related signal may slow parallel search slightly (Chun and Wolfe, 1996).

The primary hypotheses for this study should be similar to those of visual search for serial and parallel searches. Because distractors (tail lamps) and targets (brake lamps) in the currently mandated lighting share the same color and are only differentiated by brightness which is attenuated by various factors, the hypotheses for the current lighting (red tail lamps with red brake lamps) are the same as for a serial search. If changing the tail lamp color sufficiently homogenizes the distractor set and categorically differentiates it from the target brake lamp, both alternative rear lighting systems (two kinds of amber tail lamps with red brake lamps) can be categorized as efficient (parallel) searches. If these assumptions are accurate, set size manipulation will have differential effects on performance both between and within conditions and the following hypotheses (which are diagrammed in Fig. 1) based on a search model by Chun and Wolfe (1996) should hold. All of these predictions are made with the key assumptions that ambient lighting is comparable to civil twilight and the driver is distracted and has missed brake lamp onset.

2. Method

2.1. Participants

Forty-eight English speaking Clemson University undergraduates (18 male; mean age = 20; SD = 2.3) who were licensed drivers