Capturing attention to brake lamps

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Abstract

Rear-end collisions and distraction are major concerns and basic research in cognitive psychology concerning attention in visual search is applicable to these problems. It is proposed that using yellow tail lamps will result in faster reaction times and fewer errors than current tail lamp coloring (red) in detecting brake lamps (red) in a “worst case” scenario where brake lamp onset, lamp intensity and temporal and contextual cues are not available. Participants engaged in a visual search for brake lamps in two conditions, one using red tail lamps with red brake lamps and one with the proposed combination of yellow tail lamps with red brake lamps in which they indicated by keyboard response the presence or absence of braking cars. The hypothesis that separating brake and tail lamps by color alone would produce faster RTs, reduce errors, and provide greater conspicuity was supported. Drivers and non-drivers detect absence and presence of red brake lamps faster and with greater accuracy with the proposed yellow tail lamps than red tail lamps without the aid of any of the aforementioned cues. Vehicle conspicuity will be improved and reductions in rear-end collisions and other accidents will be reduced by implementing the proposed yellow tail lamp coloring.

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Keywords: Rear-end collisions; Brake lamps; Tail lamps; Visual search; Conspicuity

Approximately two million rear-end collisions occur in the United States each year resulting in billions of dollars in economic loss, nearly one million personal injuries and around 2000 fatalities, constituting roughly 25% of all accidents and approximately 5% of fatalities (NHTSA, n.d.-b; NTSB, 2001; Sullivan and Flannagan, 2003). There are a variety of approaches to reducing these numbers. Systems to monitor driver arousal as well as countermeasures involving Intelligent Transportation Systems (ITS), such as adaptive cruise control (ACC) and collision warning system (CWS) are being studied intensively. While these systems hold great potential promise, their implementation may be many years away. Additionally, because driving relies heavily on visual stimuli, it seems logical to examine the effectiveness of the present visual cues provided by automobile lighting in capturing attention to brake lamps.

Presently, the visual stimuli used to alert drivers to a stopped or braking vehicle are cues of the color red, the change in intensity from a tail lamp to a brake lamp, and since 1995 the unique location of the lamp (on most, but not all vehicles) in the form of a center high-mounted stop lamp (CHMSL). The vehicle lighting standard is mandated by the National Highway Traffic Safety Administration (NHTSA) under Title 49 of the United States Code, Chapter 301, Part 571, Federal Motor Vehicle Safety Standards (FMVSS), Standard No. 108, Lamps, Reflective Devices, and Associated Equipment (NHTSA, n.d.-a). The stated purpose for Standard 108 is to “reduce traffic crashes and deaths and injuries resulting from traffic crashes . . . by enhancing 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” (NHTSA, n.d.-a). According to the Standard 108, the functional purpose of the tail lamps is to indicate the vehicle’s presence and width. The functional purpose of the brake lamps is to indicate braking. Both tail lamps and brake lamps are required to be red, on the rear of the vehicle, symmetrical, and as far apart as is practicable.

Although brake lamps and tail lamps have different functions, they are required to share the same color. To compensate for this color similarity, luminance and location cues have been added to brake lamps. While differing luminance may seem to increase conspicuity, luminance cues are moderated by a variety of environmental factors such as ambient lighting conditions, distance from the source, vagaries of size, shape, and number of bulbs used on different vehicles and the limitations of subjective

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human perception which prove faulty when judging absolute differences (Wickens et al., 1998). Redundancy of lamps is also unable to compensate for color similarity when one or more vehicle lamps are obstructed from view. With the present color system, the illumination of one corner red lamp could indicate braking, turning, or simply a vehicle with its lights on. Additionally, the initial benefit resulting from the novel change in location provided by the CHMSL has reportedly lost much of its effect since its inception (NHTSA, 2002). The red color requirement for tail lamps has also constrained ideas aimed at increasing conspicuity such as with daytime running lights (DRLs). The implementation of DRLs has not included rear illumination because of tail and brake lamp similarity. This has had the net effect of actually compromising conspicuity of the rear of vehicles during the daytime which may include dim lighting conditions such as overcast skies and fog.

Requiring two lamps with different meanings to share the same color is very problematic if detecting brake lamps is understood as a visual search task. A large body of research investigating how people search a visual scene indicates that in order to automatically capture attention to a target (in this case brake lamps), the target must differ from its potential distractors (here, tail lamps) on salient dimensions, such as color (Treisman and Gelade, 1980; Treisman, 1986). If features are shared by target and distractors, such as being the same color, cognitive resources are needed to search the visual field to locate the target. In this situation, as the number of distractors increase, so does the duration of the search. On the other hand, if the target is a feature singleton and does not share properties such as color with distractors, few attentional resources are needed to detect the target. In fact these salient features are said to make detection of the target stimulus “preattentive” such that a search is preempted. The target is said to “pop-out” of the visual field and increasing the number of distractors does not lengthen the time needed to detect a target (Treisman and Gelade, 1980; Treisman, 1986). Thus, the shared feature of color for tail, directional and brake lamps makes the search for a brake lamp a conjunctive search that impairs brake lamp detection. Seeing red lamps without the attendant consequence of braking becomes a nearly perpetual experience for drivers because of this redundant use of red. Because of the conflicting meanings of presence, width, braking, and direction connected to the color red, drivers cannot use a simple search strategy based on color as a predictive cue of braking. Rather, they must detect multiple cues in a search that is complex, effortful and inefficient. The task is really no longer detection of brake lamps but discriminating between multiple red lamps.

Beginning in the 1960s it was recommended to the NHTSA to separate the function of rear lighting on vehicles by the dimension of color using yellow for tail lamps and red for brake lamps only (NHTSA, 2002, 2003). More recently, another study found that using yellow tail lamps would improve brake lamp detection. Cameron (1995) examined the use of yellow tail lamps with red brake lamps instead of the conventional use of red tail lamps and red brake lamps in a system he called red light means stop (RLMS). Subjects were tested on detection of activation of rear lighting while performing distraction tasks as they sat in a car viewing the rear of another stationary vehicle during daylight and nighttime conditions. His results showed faster RTs and reduced errors for the RLMS (yellow tail lamps/red for brakes only) compared to conventional lighting.

There is good reason to test the performance of brake lamp detection without moving vehicles as did Cameron (1995). There are a number of other visual cues that a lead vehicle is braking that are independent of vehicle lighting. A stop sign or red light at an upcoming intersection provide contextual cues of the need to brake that may precede or even supercede lead vehicle brake lamp activation. Spatio-temporal cues such as rate of closure on lead vehicle, lead vehicle pitch and the looming cue of increasing vehicle size on the retina may indicate lead vehicle deceleration. Because it is possible that the temporal, spatial and contextual cues are the primary indication of braking used by drivers, in order to examine the effectiveness of Standard 108 in aiding brake lamp detection, the standard should be initially tested in the absence of these cues.

Given the stated purpose of Standard 108 to enhance conspicuity of vehicles such that their presence is perceived and signals understood in all conditions, the present study proposes that the present rear lighting requirements are inadequate based on cognitive psychology research. For this experiment, it was predicted that separating the functional purpose of (target) brake lamps from the functional purpose of (distractor) tail lamps on the single dimension of color would result in faster RTs, fewer errors and less variability in both measures than separating the two lamps on the dimensions of location and intensity as is done with the current lighting system when drivers do not have the cues of lamp onset and perceptual differences in lamp intensity. Thus, this experiment is testing the detection of the brake signal in a “worst case” scenario of complexity, distraction and lighting that negates cues of lamp onset, lamp intensity, and other temporal cues.

1. Method

1.1. Participants

Twenty Brooklyn College undergraduates (10 drivers: mean years driving = 7.8, mean age = 29.8, 6 female, 4 male; 10 non-drivers: mean age = 21.3, 9 female, 1 male) were recruited from an Introductory Psychology subject pool for a within-subjects experimental task. Binocular visual acuity (with corrective lenses if needed) using a Snellen chart on a self-illuminated stand at 4 and 2 m, and color vision using the Farnsworth D-15 test were evaluated for all participants prior to the experiment. All subjects included in the study had acceptable acuity at both distances (20/20 or better at 4 m) and passed the Farnsworth D-15.

1.2. Apparatus

Cedrus Superlab™ software was used to program the presentation of stimuli projected onto a screen through a personal computer and portable projector in a 3 m × 3 m unlit room with no windows and no artificial lighting. Participants sat in a chair
facing the screen holding a Cedrus Superlab™ 610 response box in both hands. The distance from the participant’s eyes to the screen was 2.43 m and the size of the display on the screen was 90 cm × 122.5 cm. The luminance on a blank slide prior to each session was 7.5 cd/m² as measured by a Pentax Spotmeter V.

1.3. Stimuli

Forty digital pictures (20 with at least one vehicle braking, 20 with no vehicle braking) of traffic scenes were presented in two conditions. For the Red condition, tail lamp color was left unedited (red tail lamps, red brake lamps). The Yellow condition pictures presented proposed lighting (yellow tail lamps, red brake lamps) using the same pictures as the Red condition but with red tail lamps replaced by yellow tail lamps edited in Adobe Photoshop™.

To test the efficacy of the brake signal independent of spatio-temporal cues, still pictures are used as stimuli in this experiment. This method also allows a more complex visual field to be presented to the driver with multiple cars and lanes of traffic under a variety of roadway conditions. Individual slides also allow detection of brake lamp onset to be precluded in order to examine performance with inattention to such an event due to previous distraction.

In order to simulate the complexity of real world driving circumstances, the traffic scenes vary in traffic conditions (highway, intersection, local), ambient lighting conditions (day and night), number of distractor vehicles (vehicles with tail lamps illuminated but not braking), and number of target vehicles (braking vehicles), as well as the location of the target vehicle(s). Pictures were taken through a vehicle windscreen and attempt to simulate the perspective of a following driver. All identifying markers such as road signs, license plate numbers, and personal images were obscured with computerized editing.

1.4. Reaction time data

Because this study examines the relative conspicuity of brake lamps between two conditions, regards the brake lamp as a signal for numerous possible responses other than braking and employs a handheld response, RTs in this experiment denote search, detection, and decision time and are not meant to be indicative of RTs for a braking response. Nevertheless, Cedrus Superlab™ software claims to have a 1 ms resolution in RT when using the 610 response box. Variability in software or hardware timing and computer screen refresh rates are deemed to be randomly distributed across trials and participants and inconsequential to the overall results.

1.5. Design and procedure

Participants experienced 40 randomly presented trials in both the Red and Yellow conditions. Participant exposure to either the Red or Yellow condition for the first block of trials was counterbalanced and followed by the opposing condition. Participants were given oral and visually presented instructions to press the left key in response to brake lamp presence on any automobile in the scene and the right key in response to the absence of brake lamps in the scene. A sample picture with only one automobile braking was presented and the experimenter asked the participant to identify which automobile in the scene was braking. A number of participants (usually non-drivers) could not initially identify a brake lamp amongst red tail lamps in the Red condition. Whether or not the participant could detect the correct vehicle, the vehicle was pointed out and an explanation given on how to identify a brake lamp. Participants were instructed to respond as quickly as they could and to be as accurate as possible. When participants indicated they understood the instructions and felt comfortable in identifying a brake lamp, they began the trials. After participants responded to each traffic scene, the test stimuli extinguished and a solid gray screen appeared for 1000 ms as an inter trial interval before the next test stimulus was presented. Correct (hits and correct rejections) and incorrect (misses and false alarms) responses and reaction times (RTs) were recorded for each event. Only trials with correct responses were included in the RT data.

2. Results

A natural log transformation of RT data was analyzed in a 2 × 2 (Color × Driver) repeated measures ANOVA. In the brake present trials mean RT for Yellow was significantly faster than Red, \( F(1, 18) = 73.24, p < .001 \), partial \( \eta^2 = .80 \). In the brake absent trials mean RT for Yellow was also significantly faster than Red, \( F(1, 18) = 47.67, p < .001 \), partial \( \eta^2 = .73 \). There was a significant interaction between driver and tail lamp color in the brake present trials, \( F(1, 18) = 4.98, p = .04 \), demonstrating that driver’s had faster RTs than non-drivers with yellow tail lamps when brake lamps were present, but no main effect of driver, \( F < 1 \). There was no significant interaction or difference between drivers and non-drivers in brake absent trials, \( F < 1 \). Fig. 1 displays mean RT (ms) and standard error (S.E.) for drivers and non-drivers in each condition.

![Fig. 1. Mean RT (ms, with S.E. bars) in brake present and absent trials for drivers and non-drivers in Red and Yellow conditions.](image-url)
Table 1
Mean number of errors and (S.D.) in brake present and absent trials for drivers and non-drivers in Red and Yellow conditions

<table>
<thead>
<tr>
<th>Tail lamp color</th>
<th>Brake present (20 trials)</th>
<th>Brake absent (20 trials)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver</td>
<td>6.9 (3.3)</td>
<td>4.9 (3.9)</td>
</tr>
<tr>
<td>Non-driver</td>
<td>9.4 (3.4)</td>
<td>4.7 (3.1)</td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver</td>
<td>1.0 (.6)</td>
<td>3.1 (1.9)</td>
</tr>
<tr>
<td>Non-driver</td>
<td>2.1 (1.1)</td>
<td>2.2 (1.4)</td>
</tr>
</tbody>
</table>

Error data were also analyzed in a 2 × 2 (Color × Driver) repeated measures ANOVA at the .05 alpha level and with signal detection calculations. For brake present trials the Yellow condition resulted in significantly fewer errors than the Red condition, F(1, 18) = 71.61, p < .001, partial η² = .79. In the brake absent trials there was no significant difference between the two conditions, F(1, 18) = 3.91, p = .06. Significantly fewer errors were committed by drivers in the brake present trials, F(1, 18) = 5.37, p = .03. No difference between drivers and non-drivers was found in the brake absent trials, F(1, 18) = .42, p = .53. Table 1 displays mean errors and S.D. for drivers and non-drivers in each condition. Table 2 displays signal detection results for all participants indicating the Yellow condition had greater sensitivity for target detection than the Red condition (see Figs. 2 and 3 for sample stimuli).

3. Discussion

The results support the hypothesis that separating the function of tail lamps and brake lamps by color significantly increases conspicuity of brake lamps, reduces RT and error rates (misses and false alarms) compared to the current lighting system, when drivers do not have the cues of lamp onset and perceptual differences in lamp intensity. The brake lamp is understood to be an occasion setting discriminative stimulus that can evoke multiple responses (e.g. no action, deceleration, lane change, braking) determined by a multiplicity of contextual antecedent, concurrent, and subsequent stimuli (traffic signals, rate of closure on lead vehicle, following distance, road conditions, etc.) and not simply a cue for a following driver to depress the brake pedal. Thus, the results obtained for signal detection, error, and RTs are meant to assess conspicuity, not braking times.

In relation to the images used in this study, it is important to note that this study is testing the concept of conspicuity and enhanced brake lamp detection due to separating lamp function by color. The actual implementation of this proposal involves a number of issues, some of which are the realm of engineering and others psychology, that must be addressed concerning the location, luminance, size, shape, hue and duration of the tail lamp signal in combination with the brake lamp. While some of these issues are implicit in the photographs, they are only one example of many possibilities. Also, because the proposed lighting color change has no previously mandated luminance level or hue and these are viewed as a subjective phenomenal experience dependent on a multiplicity of contextual factors (ambient lighting, vehicle design, etc.) no attempt is made to examine relative luminance of tail and brake lamps for every possible scenario. Rather, target brake lamp luminance is simply held constant between conditions so comparison can be made between proposed and current lighting.

While the overall result of faster RT and reduced error for the proposed lighting are the same as found by Cameron (1995) and others (NHTSA, 2002) the current methodology has attempted to extend these findings by examining the proposal in a “worst case” scenario in which lamp onset and intensity are not cues in a context of greater complexity. While other studies (Cameron, 1995; Wierwille et al., 2006) have employed distractor tasks, this does not guarantee the participants were distracted at the crucial moment of stimulus onset. Driver distraction is a major factor that must be considered when examining brake lamp detection. The AAA Foundation for Traffic Safety enumerates 13 categories of driver distraction some of which are unrelated to the

Table 2
Signal detection results combining all participants

<table>
<thead>
<tr>
<th></th>
<th>Hits (%)</th>
<th>False alarms (%)</th>
<th>d'</th>
<th>Beta (ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>.92</td>
<td>.13</td>
<td>2.54</td>
<td>1.47</td>
</tr>
<tr>
<td>Red</td>
<td>.59</td>
<td>.24</td>
<td>.94</td>
<td>.80</td>
</tr>
</tbody>
</table>

Fig. 2. Sample slide: red tail lamp condition.

Fig. 3. Sample slide: yellow tail lamp condition.
employed the brief visual disruption of a simulated driving envi-
recent study used a dynamic change blindness paradigm which
the likelihood that attention to stimuli of critical importance will
attention will be divided between multiple tasks and decreases
novel events. This dynamic all but guarantees that a driver’s
experienced drivers give little attention to driving and more to other
tasks, with the automated processes receiving fewer resources
than novel tasks (Sternberg, 2003). Thus, new drivers may have
their attention taxed because of division of resources while expe-
rienced drivers give little attention to driving and more to other
novel events. This dynamic all but guarantees that a driver’s
attention will be divided between multiple tasks and decreases
the likelihood that attention to stimuli of critical importance will
be sustained. By using individual presentations of stimuli, the
present method presupposes distraction and is able to exam-
ine how a driver might respond upon having redirected their
attention to the visual field after brake lamp onset. Similarly, a
recent study used a dynamic change blindness paradigm which
employed the brief visual disruption of a simulated driving envi-
ronment in order to mimic glances away from the roadway (Lee
et al., 2007).

This study is in no way meant to be the final word or the defini-
tive study on which to base internationally recognized vehicle
lighting standards. Larger scale studies must be conducted in
real world environments. The large differences in performance
between the two conditions as evidenced by the signal detection
results and the large effect sizes demonstrated ample statistical
power for the use of 20 subjects in this initial study and provide
a starting point for sample size. Another important consider-
ation is the complexity of the visual field in this experiment
compared to previous studies. In other experiments (Cameron,
1995; Wierwille et al., 2006) a single vehicle directly in front of
the subject was the sole source of information about traffic con-
ditions. Future studies must employ a more complex visual field
with multiple cars in a variety of traffic situations to examine
how brake lamps are detected at various locations and distances
and with partial occlusion. This may be unlikely when using
a closed track with a single lead vehicle. Unfortunately, most
if not all driving simulators have not been engineered to allow
users to modify tail lamp color, as this was not seen to be a
needed manipulation. However, research using sleep deprived
subjects, color blind subjects, eye-tracking equipment, vigilance
tasks and re-engineered driving simulators is being pursued to
examine the predictions of visual search theories as they apply
to this proposal.

The RTs for the Red condition are so delayed as to suggest that
amid conditions of distraction and suboptimal lighting, drivers’
are using other spatio-temporal cues to determine if vehicles are
braking. If this is the case, the brake signal with its shared color
is not accomplishing its intended purpose as the primary early
warning signal that a lead vehicle is braking. Perhaps because
the current lighting does not provide early warning, the NHTSA
is presently examining other lighting schemes to reduce rear-
end collisions that do not involve separating lamp function by
color (Wierwille et al., 2006). Unfortunately, the same strategy
of increasing conspicuity by adding more cues to the target brake
lamps to compensate for the shared color with tail lamps is the
focus. In addition to the current brake lamps, a flashing lamp
has been suggested by the NHTSA as an imminent warning sys-
tem for abrupt braking. While cues to indicate rate of vehicle
deceleration may be of benefit, this new feature is being con-
considered without solving the underlying problems inherent in
the present lighting standards. Because the color red is still shared by
directional, tail and brake lamps, adding another light does not
address current conspicuity problems during less severe braking,
obstruction, with DRLs, poor ambient lighting, and distraction.

Because the NHTSA is presently considering altering the
brake signal, it is imperative to reconsider the issues addressed
in this study. Conspicuity and capture of attention is enhanced by
making the red brake lamp a feature singleton target in a visual
field filled with yellow distractor tail lamps. Because yellow
tail lamps constrain and guide drivers’ visual attention so that
brake lamps are detected effortlessly, this may also reduce driver
fatigue. The search strategy used for this type of feature singleton
is unaffected by number of distractors, location, ambient lighting
conditions, and partial obstruction (Treisman and Gelade, 1980;
Treisman, 1986). Thus, problems of conspicuity affecting the
current lighting are overcome by the proposed lighting system.
Simply, any red light, at any location or intensity, whether seen
at onset or not, is indicative of vehicle braking.

Pilot studies have shown that even a relatively small introduc-
tion of the yellow tail lamps (10% of vehicles) into the current
lighting scheme will significantly benefit brake lamp detection.
The impact of introducing such a change into the system should
be analogous to the introduction of CHMSL. The NHTSA study
on the introduction of CHMSL estimated a reduction of over
200,000 crashes per year with a reduction of 58,000–70,000
injuries per year and associated costs of US$ 655,000,000 while
adding US$ 206,000,000 of annual costs to consumers. Initially
the program reported a significant reduction in rear-end collis-
ions. However, the NHTSA admits the effectiveness of CHMSL
has declined substantially (NHTSA, n.d.-b, 2002). This study’s
proposals should result in benefits equal to or greater than ini-
tially proposed by the CHMSL study with no greater costs and
proposals should result in benefits equal to or greater than ini-
tially proposed by the CHMSL study with no greater costs and
proposals should result in benefits equal to or greater than ini-
tially proposed by the CHMSL study with no greater costs and
the subsequent decline in effectiveness because the pro-
posed system operates on principles of preattentive capture of
attention and not simply on novelty.

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