Novel Automotive Lamp Configurations: Computer-Based Assessment of Perceptual Efficiency

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ABSTRACT

Perceptual studies on pedestrians and bicyclists have shown that highlighting the most informative features of the road user increases visibility in real-life traffic scenarios. As technological limitations on automotive lamp configurations are decreasing, prototypes display novel layouts driven by aesthetic design. Could these advances also be used to aid perceptual processes? We tested this question in a computer-based visual search experiment. 3D rendered images of the frontal view of a motorbike and of a car with regular (REG) or contour enhancing (CON) headlamp configurations were compiled into scenes, simulating the crowding effect in night-time traffic. Perceptual performance in finding a target motorbike (present in 2/3 of all trials) among 28 cars of either condition was quantified through discriminability, reaction time, and eye movement measures. All measures showed a significant perceptual advantage in CON vs REG trials. Results suggest that facilitating object perception in traffic by highlighting relevant features of vehicles could increase visual performance in both speed and discriminability. Furthermore, the associated gain in eye movement efficiency may decrease fatigue. Similar methods, with varying trade-off ratios between fidelity and low-level control, could be applied to design the most ideal lamp configuration for traffic safety.

CCS CONCEPTS

• **General and reference** → **General conference proceedings**; • **Human-centered computing** → *Empirical studies in interaction design*; • **Applied computing** → *Transportation.*

KEYWORDS

automotive lighting, visual search, eye movements, object perception, scene perception

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1 INTRODUCTION

All road users want to be seen – and generally, the brighter lights they have at night, the safer they feel. Adequate perceptual performance in night-time traffic, however, relies on many factors beyond low-level saliency, and intuitive assumptions about these higher-level processes can be misleading. Bicyclists, for example, commonly believe that wearing a fluorescent vest or electric lamps on the bicycle give them exemplary visibility [Wood et al. 2009, 2013], while the placement of these markers is actually far from ideal. Studies on pedestrians [Tyrrell et al. 2009; Wood et al. 2005] show that the most informative locations to highlight are the ones which carry cues of biological motion, with crucial emphasis on the feet (see also e.g. [Troje and Westhoff 2006; Wang et al. 2014]). Similarly, in case of a bicyclist, visibility of moving parts of the body increases perceptual performance in realistic scenarios [Hemeren et al. 2017; Wood et al. 2012], and visual emphasis on a motorcycle's key features may also facilitate its detection [Ranchet et al. 2016; Rößger et al. 2012]. Therefore, distributing the same 'amount' of light differently across different parts of a road user can affect safety on the road.

One explanation for such findings is that perceptual comprehension of a complex scene requires not only detection of low-level features but also recognition of objects and their dynamic relationships. When a driver in night-time traffic detects a single point of light source, several ambiguities need to be resolved until this level of perceptual understanding is reached: distance, size, or velocity cannot be directly derived from a point-like light source without additional cues. Accurate predictions in traffic may also rely on identification of the type of road user in sight. In case of a pedestrian or bicyclist, object perception is aided by cues of motion, where moving parts are prototypical for the road user class. Correlated movement of various parts can also help the perceptual reconstruction of object structure [Marr and Nishihara 1978] from its visually isolated parts (e.g. retro-reflective patches or electric lamps). There is an uneven distribution of information content carried by the various parts of the object and methods of studying biological motion are able to tease apart the role of these cues in the perception of terrestrial animals [Troje and Chang 2013].

Furthermore, the perceptual step of integrating visually separate parts into a coherent object does not only open up possibilities for incorrect perceptions, but also demands processing time and effort. As a practical consequence in traffic situations, highlighting the shape of the rear of trucks with retro-reflective tape improves their visibility [Lan et al. 2019], even though the width and position of the vehicle are clearly discernible based on the two tail lamps alone.

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Can we deploy the principles above to optimize the appearance of cars for traffic safety? Current automotive lamp configurations are based on obsolescent technologies, with which the possibility for shaping the light source was limited and therefore the most informative lamp locations were at the corners of the car. These lamp locations are also fixed by regulation, but technology has moved on to creating nearly endless possibilities for shaping most lamp types. While primary light sources have become smaller (thereby increasing glare and depth-ambiguity at shorter viewing distances [Bullough and Hickcox 2012; Lopez-Gil et al. 2012; Sivak et al. 1990; Ziegelberger 2013]), light guides allow daytime running lamps (DRLs), side marker, turn-signal and tail lamps to have arbitrary shape and surface area. While production models are limited by regulation, automakers go creative with these technologies in prototypes (e.g. by connecting the two headlamps with various light patterns; see also [Albou et al. 2019; Raciniewski et al. 2020; Ramos 2018; Sturmat 2019]), alluding to a likely change of regulation in the foreseeable future. With glare and distraction monotonously increasing on the roads and the spread of DRLs already having elicited polarized reactions, some may fear that this future is destined to be primarily governed by aesthetic design and sales considerations. New technologies, however, can also open up new ways to increase perceptual efficiency, thereby reducing the (rational or emotional) need for further magnifying the glaring and distracting properties of vehicle lamps.

Here we aim to explore whether classical paradigms for studying object and scene perception could be used to aid the design of lamp layouts in achieving better perceptual performance and, eventually, increased traffic safety. A visual search task was used, with frontal views of cars (in the role of distractors) and a target motorbike compiled into randomized visual scenes. These stimuli display crowding and masking effects (see Figures 1 & 2), thereby aiming to model critical perceptual challenges of night-time traffic. In one condition, cars were rendered with regular headlights while in another condition, the contours of the car were emphasized with additional light elements, imitating one possible implementation of novel running lamp layouts. If the added contour lights facilitate object perception, participants' responses will display higher discriminability of the target and shorter reaction times, with a shorter relative path of gaze movements until task completion. However, if the additional visual elements on distractor items increase visual clutter, the opposite results should be found.

Figure 1: Illustration of a visual masking scenario in traffic. Identical scenes of a car and a bicyclist rendered with different lamp layouts. Note that the silhouette of the cyclist is visible in the bottom image while it is practically invisible in the top image. (Car object is as used in the experiment, albeit with more realistic rendering for illustration purposes.)

2 METHODS

2.1 Participants

Twenty-two participants completed the experiment. One participant dropped out of analysis due to inadequate task performance (see 2.5). Participants in the final analysis were 11 women and 10 men (mean age = 28, SD = 14.11; 2 left-handed). Seven had normal and nine had corrected-to-normal vision, while five participants were uncorrected. The experimental protocol conformed to the World Medical Association Declaration of Helsinki and all participants provided written informed consent to their participation.

2.2 Stimuli

Stimulus images were based on 3-dimensional renderings (Blender v2.81; Blender Foundation, Amsterdam, the Netherlands) of one car (distractor objects) and one motorbike (target object) model. Images in all three conditions contained perspective cues according to the same camera distance and angle. Distractor stimuli in the two conditions (car with regular headlamp configuration – REG; car with additional contour lights – CON) were identical except for the absence or presence of contour lamps. To assure that the main headlamps appeared alike between target and distractor objects as well (despite their different lateral positions relative to camera), these were generated independently and the same resulting headlamp image was added to all three stimulus types.

All image silhouettes were black (0.069 cd/m^2) on grey background (0.137 cd/m^2; luminance values measured with a Mavolux 5032B light meter, Gossen GmbH, Nürnberg, Germany). Between trials, the screen was filled with the background color and a brighter grey fixation cross was presented in the center of the screen.

Displayed figure sizes varied +/- 30 % around a fixed mean: 1° X 2.5° for the target stimulus and 3° X 2.1° for the distractors. Distractor sizes were chosen randomly from this range for each trial and distractor figure. Target size was set in twenty equal steps within the above described range and only the order of presentation of target size conditions was randomized in each block. This was to assure comparability between blocks and conditions and to reduce the effect of expectation at the same time. While distractors occluded each other according to their random positions in each trial, the target stimulus was always displayed in the foreground of all distractor images so that no part of it could be occluded (Figure 2). The whole stimulus display extended 25.1° X 18.9°.

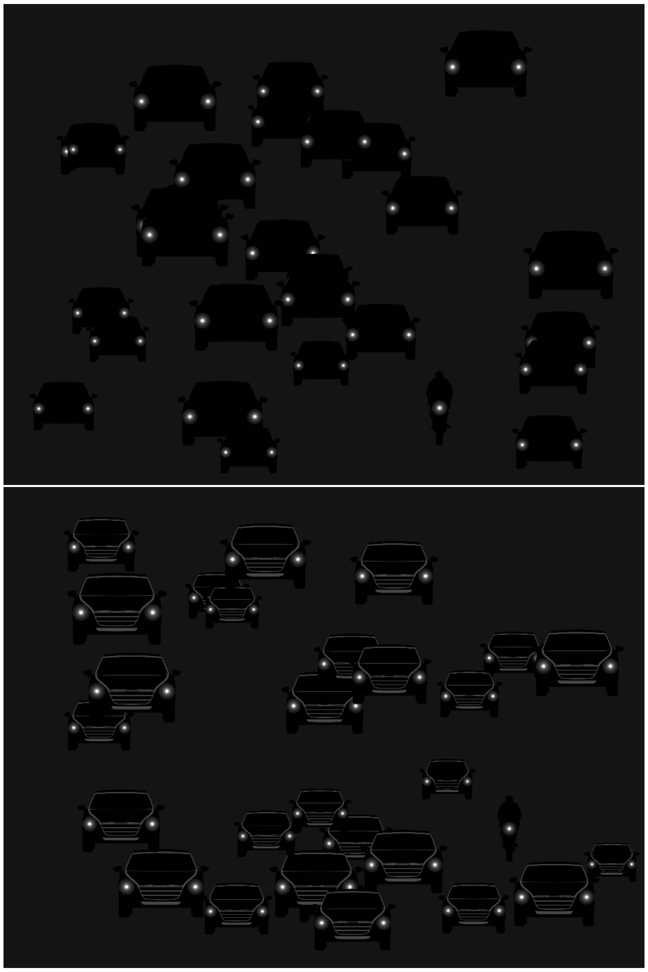

Figure 2: Example of stimulus displays. Distractor car objects are according to regular (REG; top) and contour lamp (CON; bottom) conditions.

2.3 Setup

Stimuli were presented on a VisionMaster Pro 510 CRT monitor (Iiyama Electric Co Ltd, Tokyo, Japan; 1024 X 768 pixels spatial resolution at 75 Hz) at 90 cm viewing distance, using Matlab (MathWorks, Natick, MA) and the Psychophysics Toolbox [Brainard 1997; Pelli 1997]. Eye movements were recorded binocularly with a noninvasive infra-red eye tracker at 1000 Hz (EyeLink 1000, SR Research, Ottawa, ON, Canada), using the EyeLink Toolbox [Cornelissen et al. 2002].

2.4 Procedure

Each participant completed four blocks, following an ABAB block order for the two distractor conditions (REG or CON), counterbalanced between participants. Each block consisted of 30 trials (20 signal and 10 noise trials: target motorbike image present or absent, respectively), following a randomized order.

Before the experiment, participants familiarized themselves with the three types of stimuli and assured that they were able to clearly see the silhouettes against the slightly brighter background (see 2.2) as well as all stimulus details. Standardized verbal instructions were given, which emphasized task accuracy over speed. In a training block of 9 trials (6 signal and 3 noise trials) participants practiced the task according to the stimulus condition in the first block of the experiment (REG or CON, counterbalanced across participants). At the beginning of each test block, a standard 13-point eye tracker calibration procedure was performed.

For each trial, a fixation cross presented for a randomly chosen interval of 1 to 1.5 s assured central gaze position at stimulus onset. All stimulus images (28 cars according to the given distractor condition plus 1 motorbike in signal trials) were then presented simultaneously in a static scene, where image positions were chosen randomly for each trial. Participants were instructed to search for the target motorbike image until they have either found it or ensured that there was no target in the given trial. Responses were indicated by pressing one of two buttons, corresponding to "target present" and "target absent" decisions. Upon button press, the stimulus display was replaced by the blank screen and fixation cross, leading up to the subsequent trial.

2.5 Analysis

Button press responses were analyzed regarding discriminability and reaction time (RT). For each participant and condition, rates of hits and false alarms were calculated from the proportion of "target present" responses in signal and noise trials, respectively. To measure target discriminability irrespective of response bias, d' was then calculated as the difference between z-scores of hit and false alarm rates [Stanislaw and Todorov 1999]. Rates of 0 or 1 were replaced by 0.5/n and (n 0.5)/n, respectively (where n is the number of trials in the given stimulus class [Macmillan and Kaplan 1985]). RT was operationalized as the temporal difference between stimulus onset and corresponding button press.

Eye data were analyzed by first identifying saccades (velocity threshold = 30°/s; acceleration threshold = 8000°/s; motion threshold = 0.1°) and fixations, using the EyeLink parsing software. Gaze position was defined as the mean of left and right eye positions, when both eyes' data were available. Scanpath ratios for signal trials were then calculated as the sum of saccade lengths from stimulus onset until response, divided by the shortest Euclidean distance from screen center to the center of the target.

Based on the eye data, RTs for signal trials were divided into three segments. Saccade latency was operationalized as the time

Table 1: Summary of results.

	Condition		Statistic	
Variable	Regular headlamps (REG)	Contour lamps added (CON)	*t*	*p*
d'	2.33 (0.42)	2.66 (0.49)	4.39	<0.001
Reaction time (s)	5.02 (1.67)	4.14 (1.51)	3.45	<0.01
Saccade latency (ms)	236.18 (36.01)	220.20 (30.12)	3.44	<0.01
Scan time (s)	1.64 (0.76)	1.08 (0.48)	4.34	<0.001
Verification time (s)	2.22 (1.08)	1.59 (0.98)	3.35	<0.01
Scanpath ratio	8.36 (2.63)	5.95 (2.29)	5.21	<0.001

from stimulus onset until the onset of the first saccade of the visual search. Scan time was calculated as the time from first saccade onset until first fixation on the target (fixation location within a radius of 1.5° around target center). Finally, verification time was measured as the time from first fixation on the target until button press. Trials in which the participant was not fixating at the time of stimulus presentation onset were omitted from this analysis.

Each of the above measures were compared between REG and CON conditions and across participants using paired samples t tests. To control for appreciable task performance, a cutoff of 3 SD from the group mean was applied for outlier removal based on discriminability results. This excluded one participant (d': $\text{mean}_{22\ \text{participants}} = 2.39$; $\text{SD}_{22\ \text{participants}} = 0.68$; $\text{d'}_{\text{outlier participant}} = 0.16$). All results presented are based on the remaining 21 participants.

3 RESULTS

Discriminability was significantly higher in trials of CON ($\text{d'}_{\text{mean}} = 2.66$; $\text{d'}_{\text{SD}} = 0.49$) as opposed to REG ($\text{d'}_{\text{mean}} = 2.33$; $\text{d'}_{\text{SD}} = 0.42$) conditions, showing improved task performance with the added contour lights on distractor car objects ($t(20) = 4.39$; $p < 0.001$). Responses were also quicker in CON ($\text{RT}_{\text{mean}} = 4.14$ s; $\text{RT}_{\text{SD}} = 1.51$) than in REG ($\text{RT}_{\text{mean}} = 5.02$ s; $\text{RT}_{\text{SD}} = 1.67$) trials ($t(20) = 3.45$; $p < 0.01$). The pattern of eye movements showed greater perceptual efficiency with the added contour lights on distractor cars, as expressed in shorter scanpath ratios (CON: mean = 5.95; SD = 2.29; REG: mean = 8.36; SD = 2.63; $t(20) = 5.21$; $p < 0.0001$). Furthermore, eye-movement results showed a similar relationship across all three components of RT (see Table 1).

4 DISCUSSION

4.1 Present experiment

All measures showed significant improvements in visual search behavior in trials with additional contour lights on distractor cars. A difference in the discriminability measure alludes to that, irrespective of response bias, target motorbike images were more likely to be correctly detected or correctly identified as absent. Since reaction times were lower in CON trials, this improvement cannot be attributed to a change in speed-accuracy trade-off. Shorter scanpath ratios indicate that indeed the improved behavioral performance is due to an increase in perceptual efficiency, which affects all phases of the visual search (initiation of the search, scanning of the scene until target is found, and target verification).

In this experiment, the target object was the same in both conditions: therefore, all differences can be attributed to perceptual interference from the distractor objects. This aspect of the experiment also presents one of its limitations: real-life situations are better modeled by a hybrid search task. Similarly, while using highly schematic images in a scene with no contextual elements allowed for a high degree of low-level control, using images that are rendered with higher fidelity (e.g., as in Figure 1), possibly even embedded in a realistic scene, could also bring a study of this sort closer to reality.

4.2 Further implications of a change in lamp configurations

There are several aspects of additional contour lights which could yield perceptual benefits. For example, color surrounds around a glare source, particularly those of low color temperature, can decrease discomfort glare [Sweater-Hickcox et al. 2013]. Such surrounds could also serve to guide eye movements when no other visual cues are present and provide saccade targets away from glare sources, thereby reducing dazzling and shortening the time to subsequent dark adaptation [Brown 1964]. On the other hand, a possible undesirable outcome can be that repetitive structures of high contrast may cause pattern glare. Just as with DRLs and other, existing, automotive lamp types, flicker should also be avoided as it leads to perisaccadic mislocalization [Watanabe et al. 2005] and a decrease in perceptual performance [Veitch and McColl 1995], while the resulting phantom arrays might also interfere with the repetitive patterns of poorly designed lamps. Therefore, the least glaring implementation is likely one of large luminous surface, low luminance and color temperature, and one that also displays no flicker or repetitive patterns. These aspects need to be studied separately and the hereby tested configuration does not take them into consideration.

4.3 Conclusions

The large number of car prototypes with novel lamp configurations suggests that their perceptual properties should be studied, on all levels of visual processing. Research on biological motion perception [Troje and Westhoff 2006; Wang et al. 2014] and visibility of vulnerable road users [Hemeren et al. 2017; Tyrrell et al. 2009; Wood et al. 2005, 2012] have already indicated that facilitating object perception in traffic by highlighting relevant and informative features can increase visual performance. Our study shows that this line of thinking can also be extended to static features, like contours that highlight the prototypical shape of a car. Through crowding and masking effects, as well as through drawing different amounts of attention from finite resources, various objects of a visual scene are in perceptual interaction. These interactions explain our finding of improved perceptual performance on a motorcycle object when it is surrounded by cars whose unique features are emphasized. Understanding such processes is crucial for minimizing the dangers pertaining vulnerable road users [Rößger and Lenné 2017], who are particularly at risk in dim conditions [Fors and Lundkvist 2009]. Computer-based paradigms of classical psychology offer a cheap and quick way of gathering basic knowledge that could aid in designing the most ideal implementation of next-generation automotive lights.

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