

Exploring Feedback using Ambient Lighting to Improve Driver Attention

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SUMMARY

In-vehicle ambient lighting offers potential as an implicit interface for supporting driver attention, yet its effectiveness in this application is unclear. This exploratory driving simulator study investigated how visual attention feedback using ambient lighting was perceived by drivers. Twelve drivers completed a car-following task while engaging in a forced visual distraction task under three ambient lighting conditions: discrete flashing, temporal change and colour change. Post-drive interviews guided by the Critical Decision Method examined their perception, comprehension and projection of the different states. While most drivers noticed the lighting, few correctly interpreted it as attention feedback, and no consistent reduction in visual distraction was observed. Findings suggest that ambient lighting alone is insufficient to reallocate driver attention without clearer meaning and behavioural alignment.

KEYWORDS

Ambient lighting, driving, driver attention

Background

In-vehicle ambient lighting refers to strategically located illumination – typically, low intensity LED strips or panels – in a vehicle’s interior. These are often placed away from the driver’s direct line of sight (for example, in the footwell or door panels), but may also appear in the dashboard, and are primarily intended to capture the driver’s peripheral attention. In-vehicle ambient lighting typically has an intended purpose that extends beyond enhancing aesthetics, with previous research suggesting that ambient lighting may have several significant positive influences on space perception, interior attractiveness, perceived safety, functionality and perceived interior quality (Caberletti, 2010). In addition, different colours have been shown to influence emotional/affective responses of vehicle occupants, supporting the notion that interior lighting enables mood customisation (Kim et al., 2022).

In-vehicle ambient lighting can also be used to convey dynamic, situation-dependent information to the driver, for example, to indicate the braking intensity required to safely support a specific manoeuvre (Lacquai et al., 2011), to provide spatial information about surrounding traffic and vehicle positioning during lane-change manoeuvres (Löcken et al., 2015), or to guide driver attention towards relevant traffic objects or hazards (e.g., vulnerable road users) (Gonçalves, et al., 2023; Pfromm et al. 2013). It has also been explored as a means to convey automation status and takeover messages associated with higher levels of vehicle automation (Gonçalves, et al., 2023).

Ambient lighting is a form of Ambient Intelligence (AmI), which refers more broadly to digital environments that are sensitive, adaptive, and responsive to the presence and needs of people. AmI systems have been integrated into many everyday contexts, including homes, classrooms, and hospitals, where they monitor and detect users’ behaviour and advise or intervene to increase

engagement or enjoyment, enhance wellbeing, or reduce cognitive load (Augusto et al., 2013). A key evolution in AmI interface design is the move from *explicit* interaction – requiring direct user input – to *implicit* interaction, where the system infers user needs based on their behaviour or environmental cues, and acts accordingly (Schmidt, 2000). The design of AmI systems is therefore crucial, as they need to mediate user interaction with pervasive systems in ways that are intuitive, context-aware and minimally obtrusive (Dunne et al., 2021). This raises important questions of perception, comprehension and projection. The integration of ambient lighting into vehicles presents further unique challenges as the technology must be embedded into the environment without disrupting the primary driving task. The current study aimed to explore the use of different ambient lighting effects to improve driver attention.

Method

A within-subjects study was conducted in the driving simulator at the University of Nottingham with 12 experienced drivers.



Figure 1: Driving simulator showing location of LEDs displaying blue (L) and red (R) illuminations

Ambient Lighting

Three LED lighting strips were installed on the driver and passenger doors and across the dashboard and glove compartment to correspond with current, common implementations of such displays in vehicles (e.g. Audi, 2024) (Figure 1). The LEDs were controlled remotely in real time using an app on a mobile phone, which enabled the researcher to switch between different pre-programmed effects in response to driver behaviour, with changes effectively occurring instantaneously. Three lighting effects were created – discrete flashing, temporal change and colour change.

In the discrete condition, the LED lights remained dormant while the driver's visual attention was directed towards the road. If the driver became distracted, the lights illuminated and flashed red (on for .2s; off for 1.6s). In the temporal change condition, the LEDs were illuminated with steady blue lights while the driver was visually attentive but flashed blue when they became distracted. Finally, in the colour change condition, the lights changed from steady blue to steady red when the driver's attention moved away from the road (Figure 2).

Lighting effects were selected based on a review of the literature, which shows that dynamic warnings are generally more noticeable than static warnings. This is because human sensory systems are more sensitive to change than stasis. In particular, flashing light cues have been shown to be highly salient and effective in automatically capturing visual attention (Cass et al., 2011). This enhances the probability that a warning will be noticed and encoded by users. In contrast, colour change offers a more subtle alternative, motivated by concerns that highly salient signals may contribute to driver overload in a driving context (Einhäuser et al., 2024; von Mühlénen & Conci, 2009).

Colour-based cues have also been adopted in prior research examining the use of ambient lighting displays to convey safety-related information (Laquai et al., 2011). Both the temporal change and colour change conditions provided continuous feedback but differed in their level of visual salience. Red was used to indicate a warning state, reflecting its strong association with danger and hazard signalling (Pravossoudovitch et al., 2014). Blue was selected as the default state in the temporal and colour change conditions due to its generally positive affective associations (Elliot & Maier, 2014). To control the frequency of state changes within each condition, the ambient lighting remained blue in the temporal change condition, with warnings conveyed solely through temporal modulation rather than colour transitions.

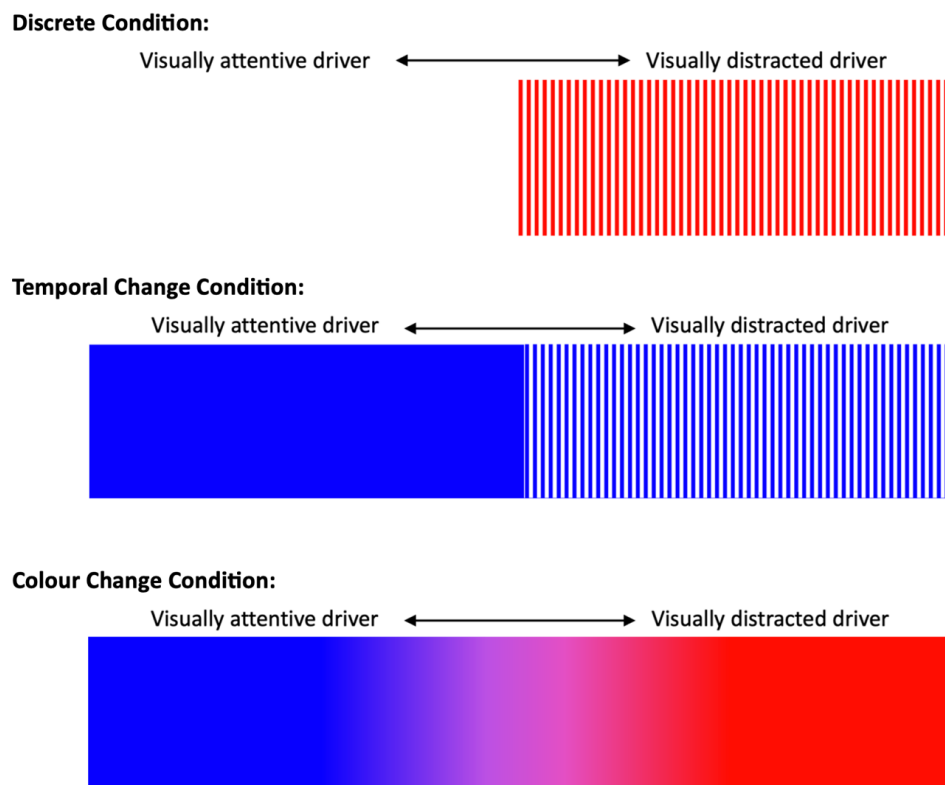


Figure 2: Graphical representation of LED lighting effects

Forced Distraction Task

The study design was predicated on the driver becoming visually distracted. A forced distraction task based on that employed by Smith et al. (2023) was therefore used to capture drivers' visual attention and encourage them to look away from the road. In this task, random letters appeared on a screen in the centre console, located to represent an in-vehicle display (Figure 3). The letter changed every tenth of a second. This allowed sufficient time for participants to perceive changes taking place, but not to identify individual letters. At random intervals, a letter remained visible for a longer duration (.4s) – long enough to be readable. The participant's task was to identify the persistent letters and read them aloud. Random intervals between persistent letters ensured that drivers could not predict the timing of the next letter and therefore had to direct their full visual attention to the task. In the original application, Smith et al. (2023) used the task to systematically control how long participants looked away from the forward roadway to view in-vehicle displays (1s, 2s, 5s), after which time they were able to return the gaze to the roadway. In the current study, the aim was to keep the driver sufficiently distracted to enable the contextually appropriate deployment of one of the ambient attention lighting effects. In order to avoid a conflict between primary and secondary tasks, drivers were reminded that safe driving remained their priority.



Figure 3: Interior of car showing forced distraction task and red lead vehicle visible on road ahead

Procedure

Participants undertook three 6-minute drives in a geotypical UK motorway scenario created using AV Simulaton SCANeR software. The car-following paradigm was used as the primary driving task (Brookhuis, et al., 1994). In this task, the participant is required to maintain appropriate speed and distance relative to a lead vehicle (the red vehicle visible in Figure 3). After approximately 2 minutes driving, the first forced distraction task was started. When drivers were deemed to be ‘visually distracted’ – defined as 15s engagement with the secondary task – the first ambient lighting effect was deployed. The ambient lighting continued for approximately one minute, intended to provide drivers with sufficient time to perceive and respond to it. After this time, the secondary task was stopped, and the ambient lights were returned to their original steady state. After a further minute driving, the forced distraction task was re-started and the ambient lighting redeployed, as before. This then occurred on a third occasion after a similar time interval. As such, the driver experienced the same ambient lighting on three occasions during the drive. A driver-facing camera captured drivers’ visual behaviour allowing post-hoc analysis of visual distraction.

After each drive, participants were asked a series of semi-structured interview questions using probes derived from the Critical Decision Method (CDM) (Klein et al., 1989). In particular, the CDM was used to elicit participants’ three levels of Situation Awareness (SA) (Endsley, 1995) and their perception, comprehension and projection in response to the ambient lighting. The driver then repeated this for the other two ambient lighting effects. The order of presentation was counterbalanced between drives and drivers to avoid learning effects.

Results and Discussion

Across all three ambient lighting conditions, most participants detected that they were visually distracted by the forced distraction task. Self-reported distraction was largely consistent with video analysis, which showed that nearly all participants exceeded Euro NCAP thresholds for visual distraction. Participant 12 consistently demonstrated the lowest eyes-off-road time and was the only participant who did not consider themselves to be distracted, indicating individual differences in cue detection and sensitivity.

Perception

With respect to the ambient lighting, perceptual awareness varied by condition. The discrete and temporal change conditions were more frequently noticed than the colour change condition, which

many participants failed to notice. Flashing lights and red colouring were generally more salient, while continuous blue lighting was often overlooked or quickly habituated to. These findings suggest that perceptual salience alone was insufficient to ensure consistent detection across participants.

Comprehension

Despite noticing the ambient lighting, very few participants correctly interpreted it as feedback about their visual attention, despite awareness of their distraction. Instead, participants engaged in alternative sensemaking strategies, commonly interpreting the lights as driving performance feedback (e.g. associated with their lane position, speed, or headway), cues linked to the secondary task (e.g. timing of letter appearance), and even random or system-driven events. Misinterpretation was evident across all conditions and explains why increased perceptual salience did not translate into behavioural change. Even participants who correctly identified the lights as attention-related believed the feedback did not correspond to their actions, undermining trust in the system.

Projection

When the ambient lighting changed state (indicating visual distraction), participants rarely made an explicit decision to reallocate their full attention to the driving task. Instead, drivers typically continued to alternate their attention between driving and the secondary task or attempted to make minor 'corrections' to their driving (e.g. speed adjustment) rather than redirecting their full attention to driving. Some participants stated that they actively decided to ignore or 'tune out' the ambient lights, while others actually increased focus on the secondary distraction task, indicating that the ambient feedback sometimes competed with, rather than supported, attentional control. Interview data supported these findings: no participant reported fully returning their attention to the road in response to the ambient lights. Partial reallocation of attention occurred in some cases but was not necessarily temporally aligned with changes to ambient lighting.

Conclusion and Further Work

Overall, results demonstrate the complexity and potential confusion caused when using ambient lighting to improve driver attention. Using a CDM lens, the results indicate that the ambient lighting effects failed primarily at the sensemaking and decision stages, rather than at perception alone. While most participants detected the cues, they did not understand their relevance or urgency, resulting in ineffective decisions and minimal behavioural change. This highlights the need to clearly communicate what is wrong and why, and to align feedback timing closely with user behaviour. Without these elements, drivers are unlikely to interpret feedback as a meaningful trigger for action, limiting its effectiveness in managing visual distraction. Results also suggest the need for more salient feedback, such as gradually intensifying the lighting effects or integrating feedback with complementary modalities (e.g. auditory or haptic cues). Conversely, the fact that flashing lights were often seen as overly distracting implies that they may be too salient and could increase cognitive workload. Continuous lighting might hold most potential for use as ambient feedback, as it was preferred by some participants who deemed it to be less intrusive. Nevertheless, concerns about the placement of lights on side doors and the dashboard/glove compartment suggests these locations might be suboptimal, either because they are too distracting or too far removed from the drivers' normal line of sight to be effective in communicating important driving-related information.

It is concluded that applying a simple, singular light change when using ambient lighting is insufficient to improve driver attention. Instead, further work should seek to examine a progression in intensity or modality. Alternatively, the movement of lighting effects towards the roadway could be explored as a method to physically guide the driver's attention back to the road. Finally,

alternative locations – potentially closer to the driver’s normal line of sight, could be examined, although it is noted that this could, in itself, interrupt or disrupt the primary driving task.

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