Exploring Drivers' Visual Behaviour During Take-Over Requests

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EXTENDED ABSTRACT

The potential to engage in distracting in-vehicle activities is recognised as a major contributor to driver demand during manual driving, and comprehensive guidelines have been published and widely adopted as industry best practice (e.g. [1]). These aim to guide the design and evaluation of in-vehicle devices and tasks, whilst discouraging those that are deemed to be too visually and/or manually demanding. Such guidelines do not currently apply to HMIs and devices employed during automated driving. This is understandable, if you consider that the 'driver' is not in control of their vehicle, and therefore cannot be distracted. However, this statement only holds true in a fully-autonomous vehicle, where the driver is completely removed from the driving task and would not be expected to resume manual control at any time. While the driver remains within the control-feedback loop to some extent (i.e. during intermediate, or 'semi-automated' driving states), the risks associated with driver distraction are likely to remain.

The focus of a driver's visual attention during a take-over request (TOR) (i.e. when a request is made to transfer control from the automated system back to the driver) is therefore likely to be important, but it is currently unclear what constitutes 'appropriate' behaviour in this situation. For example, a 'takeover-HMI' can assist drivers by alerting them of the imminent need to take control, making them aware of potential hazards, and explaining the behaviour of their vehicle – factors that are critical in re-establishing situational awareness. However, engaging with the takeover-HMI requires that some of a driver's visual attention is directed towards this (rather than road) during the hand-over of control. This causes a potential conflict: if a driver's attention is directed towards the HMI, they may be distracted from critical events occurring in the real-world (outside the scope of the HMI), that may be better attended to first-hand. This suggests that HMIs associated with TORs have the potential to distract drivers, and should therefore undergo some form of distraction assessment. However, although recognised distraction thresholds for manual driving are based on well-understood metrics, and substantiated by extensive naturalistic driving data [2], no equivalent body of empirical data exist for hand-overs. Consequently, defining what constitutes 'appropriate' visual behaviour during a take-over request – and how this translates to acceptance criteria – is as yet unclear.

Method

To explore where drivers are naturally inclined to direct their visual attention during take-over requests, and provide empirical data to inform the debate, we examined drivers' visual behaviour immediately after a request had been issued to resume manual control

Figure 1. Driving simulator and congested motorway scenario used during study.

following a period of automated driving. Sixty-four drivers undertook episodes of highly-automated driving on a congested motorway scenario in a medium-fidelity driving simulator (Figure 1). The simulator was modified to mimic a vehicle with 'traffic-jam assist' proximity sensing and control. The technology underpinning such systems is already well-established, comprising adaptive cruise control and lane keeping technologies, and enables 'highly-automated' driving in congested road situations (i.e. 'traffic jams'). Such systems therefore rely upon the presence of other road users in the host vehicle's proximity, as well as lane mediation lines, to determine primary control actions.

Drivers were asked to resume manual driving from the traffic-jam assist system in four different TOR use-cases (Table 1). Each use-case was supported by a bespoke TOR-HMI (comparable between use-cases), providing an ego-centric visual depiction of the host and nearby vehicles, and the roadway ahead. In addition, drivers were provided with a text-based statement (presented on the screen) describing the behaviour of the vehicle and the required input from the driver. Finally, a count-down indicated when drivers would need to intervene. Drivers were notified of any changes or updates to the HMI via an auditory tone.

Participants completed two types of journey for each use-case – firstly, while engaged with a distracting secondary task/device (an immersive game on an iPad, demanding visual, manual and cognitive attention) ('Distracted'), and secondly, when they were encouraged to maintain vigilance with the driving scene and system monitoring task ('Not-distracted'); conditions were counterbalanced. During both drives, participants were aware that they may be required to resume manual control, given 'appropriate' notice (in line with the definition of 'highly-automated' driving [3]). Participants wore SMI eye-tracking glasses (ETG) to capture eye movements throughout the study. To ease the burden on participants, and avoid

Take-Over Request	Example	Details
Unexpected-Non-Emergency (UNE)	Loss of lane markings/traffic dispersal (where the automated system relies on these features to guide the vehicle).	5.0s hand-over with no associated braking, i.e. car coasts until driver re-engages with the primary controls.
Unexpected-Comfort Brake (UCB)	Minor sensor failure.	5.0-second hand-over, with 'comfort' braking.
Unexpected-Emergency Brake (UEB)	Critical system fault.	5.0-second hand-over, with emergency braking.
Expected-Non-Emergency (ENE)	Vehicle approaches part of the route that does not support automated driving, such as exiting from the motorway.	50-second hand-over, accompanied by a further 'take control' request delivered 15.0s prior to hand-over.

Table 1. Take-over request use-cases investigated during the study

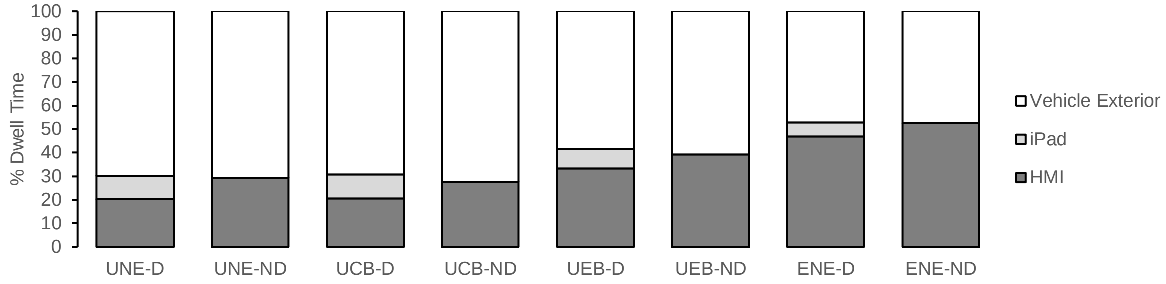

Figure 2. Percentage dwell times for each use-case (D=Distracted, ND=Not-Distracted)

multiple repeated TORs in short duration, the research was conducted as four separate, self-contained mini-studies (each employing 16 participants), and thus, results are effectively presented as 'between-subjects'.

Results and Analysis

Visual behaviour was analysed using semantic gaze mapping, with areas-of-interest (AOIs) comprising the 'take-over HMI' and 'iPad' (where appropriate) ('off-road'), and 'vehicle exterior' ('on-road'). The focus of the investigation was to consider how drivers shared their vision between the vehicle interior and exterior during the TOR, and as such, visual dwell time (rather than individual glance data *per se*) is presented (Figure 2).

A repeated-measures ANOVA comparing the percentage dwell time 'on-road' and 'off-road', shows that there were significant differences between use-cases ($F(7,105)=7.96$, $p < .001$), with drivers directing a significantly lower proportion of their vision 'off-road' for UNE and UCB, compared to both UEB and ENE. Given that UEB involved emergency braking, it is possible that drivers in this situation were seeking further information regarding why their vehicle had suddenly braked (i.e. what had constituted the emergency) – it is interesting to note that they attempted to acquire this information from the HMI and not from the 'real-world'. Similarly, drivers spent significantly longer (proportionally) with their attention directed inside the vehicle (towards the HMI/iPad) during the extended hand-over (ENE). In this situation, drivers may have expected further information regarding the impending hand-over (additional route guidance etc.), and felt there was adequate time to acquire this from the HMI before resuming manual control.

It is also evident that when drivers were actively engaged in a secondary task ('Distracted'), they continued to devote significant visual attention to this (i.e. to the iPad), perhaps to finish their current game, even after the take-over request had been made (on average between 6 and 10% of the time). Moreover, there were no significant differences between the proportion of vision directed 'off-road' and 'on-road' during Distracted and Not-Distracted conditions for each use-case. This shows that the time spent attending to the secondary task during the TOR was at the expense of attention directed to the HMI, and not to the external road scene, suggesting that there was a 'natural' balance between vision directed inside and outside the vehicle during each TOR, with drivers generally directing more attention externally (circa 70% of dwell-time for UNE and UCB).

Although it remains unclear from these data how drivers' visual behaviour during the hand-over impacted on their ability to actually resume control of their vehicle, or their subsequent driving performance (see: [4] for a detailed comparison), a clear implication of the findings is that the take-over HMI is an important factor (in terms of design and content) during take-over requests, and should therefore be considered with respect to potential distraction effects.

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