Do Hands-On or Hands-Off Drivers Perform Better During a Level-2 Silent Failure?

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SUMMARY

In a driving context, a silent failure (SF) occurs when the automated vehicle system is not able to operate but does not recognise its reduced capacity. As a result, it does not request human intervention or alert the user to the failure; the human driver must therefore recognise the need for their input and provide it in an appropriate and timely manner. Recent legislation is beginning to relax the stipulation for drivers to keep their 'hands-on' the steering wheel during level 2 (L2) automation. This study therefore explores if and how hand position ('hands-on' or 'hands-off') influences drivers' reaction time and the quality of their intervention following a silent failure at L2 automation. Results show that 'hands-on' drivers were significantly quicker to respond to the SF, with the first steering input occurring in 3.7s, on average, amongst this cohort, compared to 8.5s for 'hands-off' drivers. Significantly, all 'hands-on' drivers provided an active control input before their vehicle drifted across the lane boundary.

KEYWORDS

Level 2 automation, silent failure, hands-on, hands-off.

Introduction

There has been considerable research interest in understanding and improving the transfer of control between vehicle automation and the incumbent driver. Much of this work focusses at level 3 'conditional' automation (or higher) (SAE, 2021). It therefore applies to 'next generation' vehicles, where the driver is able to disengage from all aspects of the driving task during periods of automation and must therefore re-engage with the driving task, prior to taking manual control. In contrast, current generation vehicles are increasingly offering level 2 driver control and assistance systems (L2-DCAS) (SAE, 2021). L2-DCAS requires drivers to supervise the vehicle 'completely and continuously' while the system is in control and are therefore generally considered to be 'hands on, eyes on' systems (i.e. the driver is required to keep their hands on the steering wheel and their eyes on the road *at all times*). In 2023, the UK Vehicle Certification Agency approved the Ford BlueCruise system as the first '*hands off*, eyes on' DCAS (also referred to as L2++) in the UK (PACTS, 2024). Although such functionality is currently limited to specific roads ('blue zones') (Ford, 2022), there is a tacit assumption that 'hands off, eyes-on' is sufficient to keep drivers appraised of the driving situation and in physical readiness to resume control if/when required. Allowing drivers to take their hands off the steering wheel during automation purportedly reduces workload (Naujoks et al., 2015), making this an attractive proposition. However, it also disconnects the driver from the perception-action cycle (Cutsuridis et al., 2011), and, practically, means that their hands are now able to engage in non-driving related tasks (NDRTs) (Damböck et al., 2013), should they so desire; this, in itself can direct their attention away from the road further (Gershon et al., 2023).

It is also often assumed that in any situation outside of its control, an automated vehicle (at any level of automation) will identify its own limitation (or a malfunction) and call the driver to action. However, this will not always be the case. Indeed, it is feasible that the automation could fail in a manner not recognised by the system. It will therefore not issue a take-over request (TOR) and the driver will not be advised of the need to resume control. This is routinely referred to as a 'silent failure' (SF) and could occur if a sensor misses or misinterprets lane markings, for example, resulting in uncontrolled lane drift (see: Lambert, 2018). SFs are largely unpredictable (to both the system and the incumbent driver), and thus drivers' responses are unknown, although are expected to be slower, and the consequences and repercussions more severe, than during a planned or alerted take-over (Mole, et al, 2020).

Method

The aim of the current study is to investigate drivers' behaviour in response to a SF, as determined by their hand position ('hands-on' or 'hands-off') during the preceding L2 automation. The study took place in the University of Nottingham Human Factors driving simulator (Figure 1). AVSimulation SCANeR software was used to create a three-lane UK-motorway scenario with traffic distributed across all lanes. The simulator was modified to provide an authentic L2-DCAS experience lasting approximately 15 mins and culminating in a SF. During automation, the car performed 6 automated lane changes (effectively manoeuvring between all 3 lanes as dictated by the surrounding traffic) and braked/accelerated in response to the behaviour of other vehicles.

Figure 1: Driving simulator with AVSimulation SCANeR software

Participants

Fourteen drivers took part (7M, 7F; ages, 18-34; mean driving experience, 3.9yrs). All participants were specifically instructed to, "supervise the system automation as you would if you were manually driving", although they were not made aware of the upcoming silent failure. Seven participants were asked to keep their hands on the wheel ('hands on, eyes on'), while the remaining seven were permitted to remove their hands from the steering wheel ('hands off, eyes on'); no specific instructions were provided to the latter, 'hands-off' participants regarding whether they could engage in non-driving related tasks, for example. However, these drivers were reminded to return their eyes to the road if their off-road glances extended beyond approximately 2s, although this was not enforced precisely – the aim was to re-direct drivers' visual attention to the road if they appeared to be becoming 'inappropriately distracted' (e.g. using their mobile phone), as a driver monitoring system might behave.

In-Vehicle HMI

Prior to the SF, the system provided lateral and longitudinal control and informed the driver of its behaviour via an in-vehicle HMI, for example, declaring ‘vehicle performing manoeuvre’ using text and iconography to accompany a lane change (Figure 2). The HMI also reminded ‘hands-on’ drivers, via a text message, to replace their hands on the steering wheel if they inadvertently removed them during automation and to remind drivers in both groups to return their eyes to the road if they became distracted (Figure 2). The messages on the HMI were preprepared and controlled manually, as the situation dictated, by the experimenter from the control room.

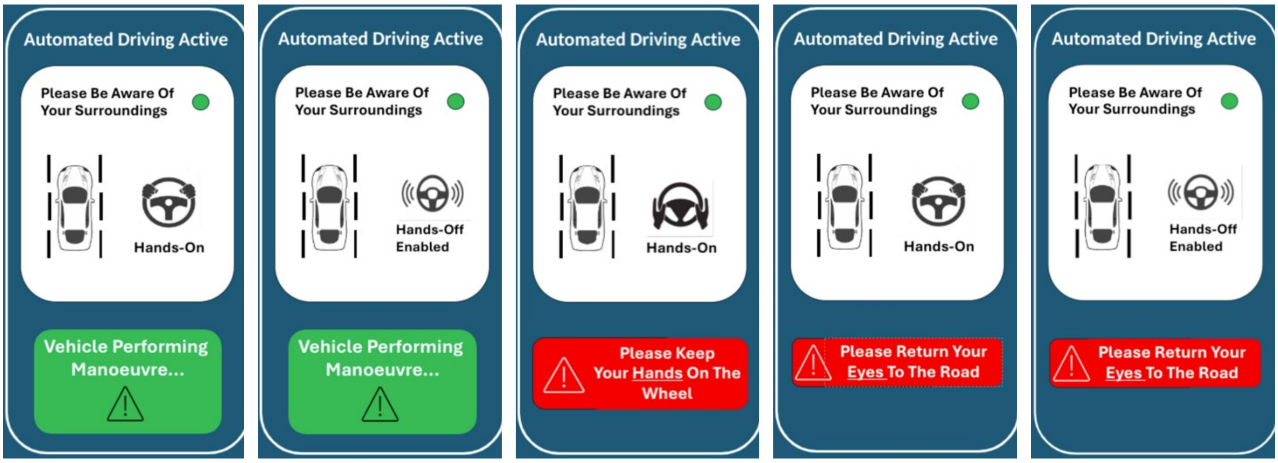

Figure 2: Example HMI screens used during periods of automation, showing (left to right): vehicle performing a manoeuvre (i.e. a lane change) for ‘hands-on’ and ‘hands-off’ drivers, a reminder for ‘hands-on’ drivers to return their hands to the steering wheel, and reminders to ‘hands-on’ and ‘hands-off’ drivers to return their eyes to the road

Silent Failure

The journey lasted approximately 15 minutes, with the SF occurring approximately 20s after the final announced manoeuvre. The SF manifested as a loss of both lateral (steering) and longitudinal (speed) control. It occurred when the vehicle was in lane 3 (right lane) travelling at approximately 70mph and had no accompanying notification on the HMI. Thus, drivers were required to detect the failure and take whatever corrective action they deemed appropriate. They were obviously not aware that a SF would occur, and no instructions had been provided regarding what to do if such a situation were to occur. If no driver intervention took place, the vehicle drifted to the left across lane 2 and into lane 1, and came to a stop in lane 1 after approx. 40s. Nearby, a ‘break-down’ truck was attending to a stationary vehicle on the hard shoulder. This was in the vehicle’s initial trajectory (i.e. when control was surrendered), and intended to present an apparent collision hazard, although no collision would have actually taken place even with no driver intervention (Figure 3). In addition, all lanes remained active with other vehicles present (as they had been throughout the journey), and thus, these vehicles also presented potential collision hazards. However, nearby vehicles acted intelligently around the ego vehicle (e.g. braking to avoid colliding with it).

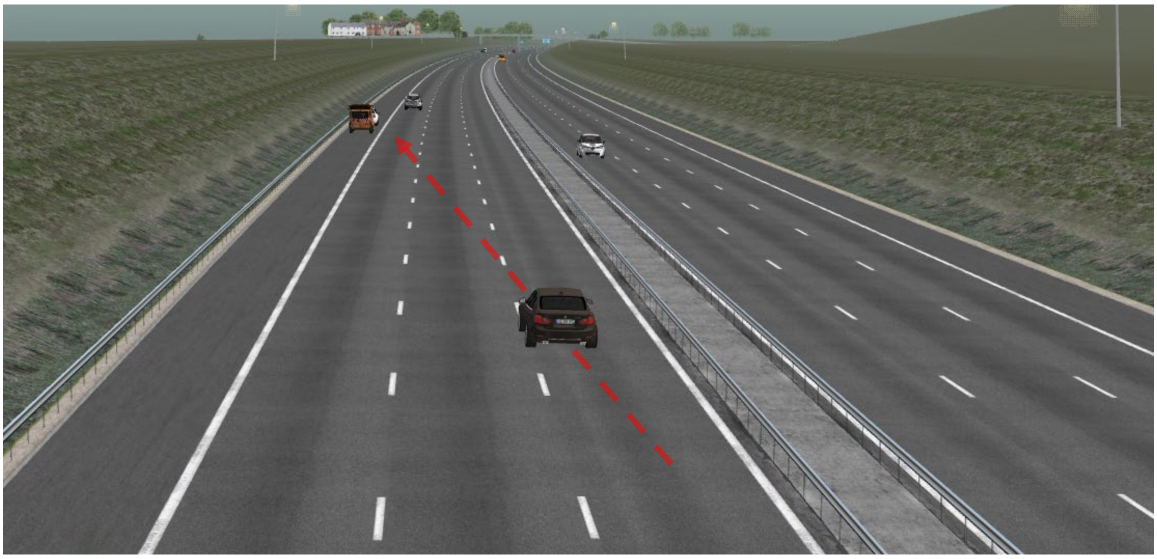

Figure 3: Image showing position of ego vehicle (black BMW) shortly after silent failure, with break-down truck attending to vehicle on hard shoulder in the ego vehicle's initial trajectory

Measures

Videographic, simulator and eye-tracking data were captured to determine participants' first response, and their vehicle control and visual behaviour following the SF. A post-study questionnaire with open-ended questions captured insights into how participants perceived their level of success at intervening and how well they felt they were able to maintain their attention on the road during automation. Unfortunately, two participants' simulator data were corrupted and thus, these participants' data were removed prior to analysis (one from each group).

Results and Discussion

Drivers' response and their reaction time was determined by their first active input to any primary control (steering, accelerator or brake), using data obtained from the simulator. For all participants (i.e. in both groups), the first active input was to steering. This manifested as either a counterwise corrective manoeuvre (presumably if they were aiming to keep the vehicle in the current lane) or a positive reinforcement of the current trajectory (if accepting the move into the adjacent lane and aiming to position their vehicle appropriately within that lane). Notably, 'Hands-on' drivers were significantly quicker to respond, with steering input occurring in 3.7s, on average, compared to 8.5s for 'hands-off' drivers (t-test, p = .02).

Vehicle trajectories during 60 seconds following the SF is shown in Figure 4. Although perhaps not immediately apparent from the graph, the initial response from all 'hands-on' drivers (Figure 4-top) occurred while their vehicle was still in lane 3 (i.e. had not crossed the lane boundary). Three of these drivers choose to remain in lane 3 by applying a counterwise corrective manoeuvre (although one of these moved to the hard shoulder to terminate their journey shortly afterwards), whereas the remaining 3 'hands-on' drivers actively steered their vehicle into lane 2, where they remained.

In contrast, five out of the six 'hands-off' drivers (Figure 4-bottom), had already crossed the lane boundary and drifted into lane 2 before reacting and providing a control input (one of these drivers subsequently moved back into lane 3 after 20s, or so). It is also notable from Figure 4 that after 30s, or so, the trajectories of 'hands-on' drivers who continued were all clustered neatly in the centre of lane 2, suggesting good lateral control. In contrast, the behaviour of 'hands-off' drivers after the same time period, appears to be more erratic, suggesting poor lateral stability, or wavering in the lane.

The first input to the accelerator or brake pedal occurred later than steering input (27s and 18s post-SF, on average, for 'hands-on'/'hands-off', respectively; as a reminder, steering input had occurred after 3.7s and 8.5s, respectively). This suggests that all drivers perceived (and 'corrected') lateral drift before noticing and responding to the retardation in speed and/or prioritised re-establishing lateral position before resuming longitudinal control. Vehicle speed during the 60s following the SF varied between individuals, with no significant difference, on average, between groups. However, it is notable that there was a tendency for drivers to accelerate above the speed limit (70mph) after taking control, with the maximum speed recorded during this time period of 82mph for 'hands-on' drivers and 90mph for 'hands-off' drivers. Respective mean speeds during the same period were 63mph and 66mph, respectively, although it is noted that some drivers were beginning to decelerate or brake towards the end of this period.

After drivers had accepted control of their vehicle, some chose to continue their journey (as evidenced by initial accelerator input), whereas others evidently planned to slow/stop the car (i.e. initially applied brakes). Three 'hands-on' and four 'hands-off' drivers chose the former strategy, whereas the remaining three/two (hands-on/hands-off, respectively) applied the brake first or allowed the vehicle to slow down passively while still controlling its lateral behaviour (one of these 'hands-on' drivers ultimately steered the vehicle onto the hard shoulder) (Figure 4). It is noted, however, that no specific instructions were provided regarding what to do if/when they were required to resume manual control during this study, and this may have influenced their behaviour.

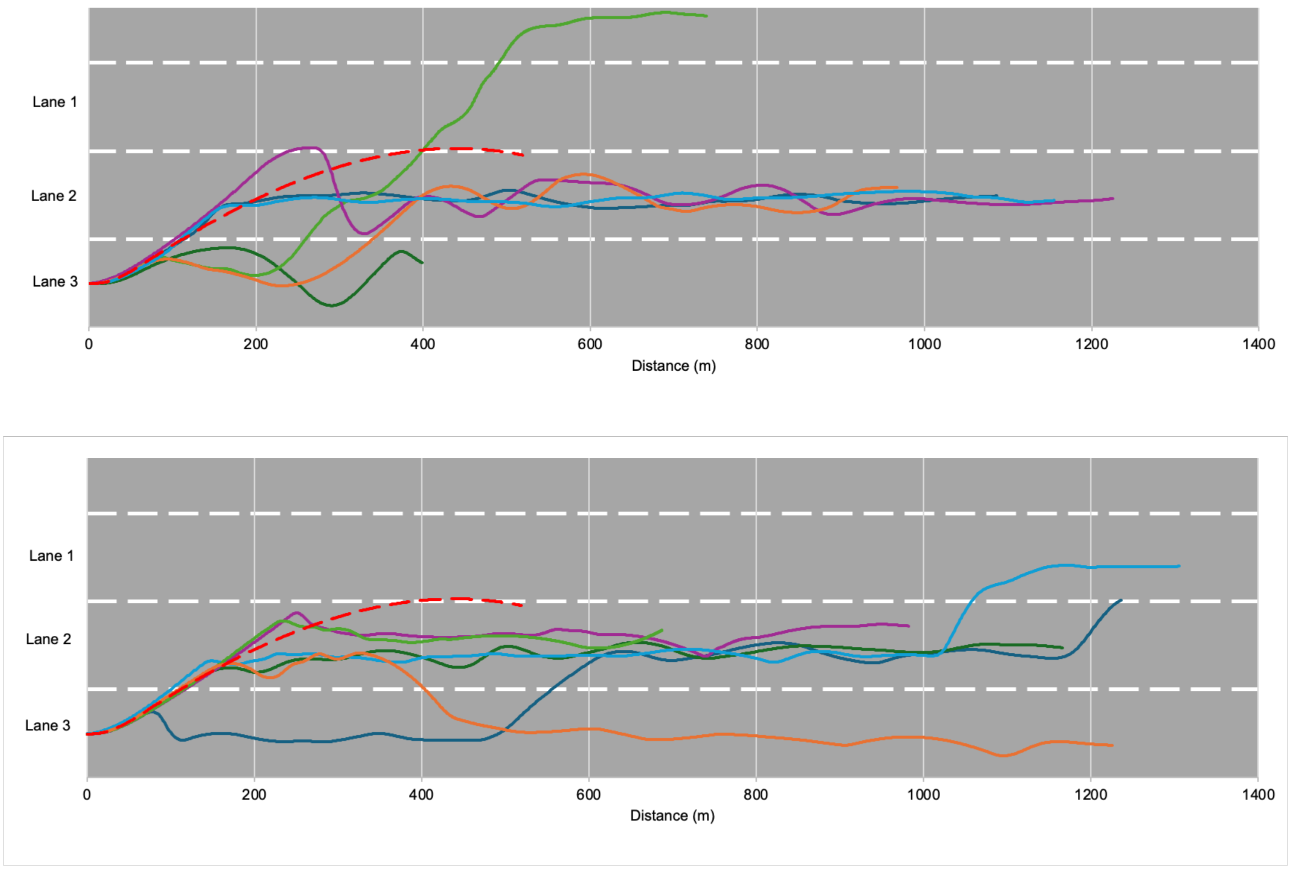

Figure 4: Vehicle trajectories during 60s following silent failure (at distance=0), showing 'hands-on' drivers (top) and 'hands-off' drivers (bottom). Note: dashed red line shows predicted trajectory of vehicle if no driver intervention took place

Visual behaviour was coded using semantic gaze mapping for 2 minutes immediately prior to the SF and 40s post SF. Results show some variability between groups (and indeed, between drivers) during both time periods, but no significant differences, on average, between groups for number and duration of fixations to different areas of interest (road scene, instrument cluster, mirrors etc.). This suggests that visual scanning behaviour had been unaffected, overall, by enforcing hand position.

Responses from the post-study questionnaire suggest that most 'hands-on' drivers believed they reacted 'effectively' when required to resume control: "I noticed the car drifting a bit, so I took control". In contrast, responses from some 'hands-off' drivers suggest that they had become complacent: "I was trusting the car too much", with some recognising that they subsequently 'panicked' when they realised that the automation system had failed and that this impacted on the quality of their takeover: "although I managed to regain control, I did panic slightly which resulted in oversteering initially and accelerating above the speed limit." In their comments, 'hands-on' drivers also generally expressed a more active role in supervising the car than 'hands-off' drivers. For example, one 'hands-on' driver commented that they applied, "the same level of visual attention as I would in fully manual driving", whereas 'hands-off' drivers' responses suggested they were more passive: "I felt my attention to the road was reduced. I felt distracted when [the car] said it was doing a manoeuvre."

Finally, a notable observation from videographic data was that several 'hands-off' participants placed their hands on the wheel during automation, ostensibly at times they perceived higher risk, for example, during high traffic flow, lane changes etc. This occurred on 16 occasions (or 2.7 times per participant), despite no specific instruction to this effect, and suggests that 'hands-on' was perceived as 'safer' by these drivers. Additionally, several drivers were observed moving their foot over the brake or accelerator pedal during automation, presumably in preparation for intervening. This occurred on 4 occasions for 'hands-on' drivers and once for 'hands-off' drivers.

Discussion

There is a tacit assumption that an automated vehicle (AV) will alert the driver and issue a take-over request (TOR) if it encounters a situation that is outside of its control. However, it is possible that the AV will not be aware of its reduced capacity (for example, due to the loss of lane demarcations or a sensor malfunction) and will therefore be unable to call the driver to action – a so-called silent failure (SF). Meanwhile, the vehicle is effectively 'unattended', with no active driver or automation system in control. This is extremely problematic, not least if the vehicle was travelling at 70mph in lane 3 of a motorway when the SF occurred. Understanding how drivers will naturally respond in this situation is therefore important in order to guide the design and development of technological solutions as well as to create supporting guidance and appropriate regulations etc.

In addition, given the general drive towards L2++ systems, and the associated relaxation of the current stipulation for drivers to keep their 'hands-on' the steering wheel during periods of automation, it remains to be seen if drivers are able to respond as effectively (in terms of their reaction time and quality of intervention) with their 'hands-off' compared to drivers with their 'hands-on' the steering wheel during periods of L2++ automation. While the study was 'between-subjects' (out of necessity, as it was exploring drivers' first response to an unexpected situation), and the number of participants was limited, it nevertheless provides some useful preliminary data to highlight this predicament.

Indeed, results show that 'hands-on' drivers were significantly quicker to detect and react to a SF, taking active (lateral) control of their vehicle in effect *before* it moved out of its current lane. In comparison, 'hands-off' drivers had typically drifted into lane 2 before responding and intervening. It is also notable that in both situations, drivers first action was to correct lateral deviation, as opposed to applying longitudinal (i.e. speed) control. Moreover, 'hands-off' drivers' vehicle control remained erratic even after 60s post SF.

Conclusion

Results from the study suggest that by keeping their hands on the steering wheel during L2 automation, drivers are better attuned to changes in the behaviour of their vehicle during automation than drivers who are permitted to remove their hands from the steering wheel. Consequently, the former, 'hands-on' drivers are better prepared to resume control if/as demanded by the vehicle or road situation, most notably, in situations such as a silent failure, where the need to take over control is both unexpected and unannounced. Future work should continue investigations with a larger cohort of participants and in a variety of driving scenarios.

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