Introducing CHAT to Improve Driver Performance during Level 3 Automated Driving

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ABSTRACT

Intermediate levels of automation will place new demands on drivers. At this level, system capability allows drivers to turn their attention to non-driving tasks, but system boundaries will require the driver to takeover control when requested and required. Drivers will need to learn how to interact and share control with the system to smoothly transition between modes of automation during dynamic operations. This study introduces "CHAT" (CHeck, Assess, Takeover) as a novel framework designed to improve drivers' performance during level 3 automated driving. It was evaluated and validated as part of a pre-drive "behavioural" training intervention, during a between-subjects driving simulator study (n=24), with drivers receiving either behavioural training or a written operating manual. Results suggest immediate, positive effects from behavioural training on drivers' tactical level task performance, most notably visual behaviour, during automated driving and transition of control, and faster disengagement from non-driving tasks following a takeover request. It is suggested that the early engagement in re-building situation awareness, demonstrated by these drivers, led to more informed and measured decision making in relation to the lane change manoeuvre immediately after takeover. Findings support the establishment of a proof-of-concept relating to this proposed training approach. Future studies will focus on further validation and using the novel CHAT procedure to inform the design and development of a human machine interface to support the uptake and maintenance of desired driver behaviours.

KEYWORDS

Vehicle Automation, Driver Training, Driver Behaviour

Introduction

Future vehicles with intermediate levels of automation (Society of Automotive Engineers level 3 (SAE, 2018)) will allow drivers to relinquish control of the driving task under certain conditions. At level 3, system capability extends from controlling driving sub-tasks at the operational level, such as the steering, acceleration and deceleration, to tactical level tasks, such as monitoring the driving environment. These automated vehicles (AVs) will likely look the same as current vehicles and a tacit assumption appears to be that current, passive modes of training (e.g. reliance on the driver reading the operating manual) will suffice (Cummings, 2019). However, while system capability boundaries remain, the driving task is one which is shared between humans and technology and the human driver is required to supervise and intervene when system limits are reached, redefining the role of, and expectations placed upon, the driver (Banks and Stanton, 2019). Therefore, it is important that drivers understand how to operate and interact with the system to safely and effectively share control of the vehicle with the automated systems (Casner and Hutchins, 2019).

A key task for drivers is that of situation monitoring or building situation awareness (SA) - continually processing perceptual information to generate an understanding and prediction of dynamic changes in the driving environment for use in physical vehicle control (Merat et al, 2019).

A pervasive challenge in vehicle automation is the inverse relationship between automation and human performance (Banks and Stanton, 2019). For example, when decision making functions become automated, the driver naturally gives less attention to the driving task, reducing SA and taking the driver 'out of the loop' (OOTL) of control. The coupling of the physical control of the vehicle and situation monitoring has recently been used to clearly define the associated OOTL problem seen at intermediate levels of automation (Merat et al., 2019). The so-called 'in', 'on' and 'out of the loop' state definitions are useful when thinking about the interrelationships between the driving task, the role of the driver and level of vehicle automation. According to these definitions, 'in the loop' is defined as in physical control of the vehicle and monitoring the driving situation, OOTL is defined as not in physical control of the vehicle and not monitoring the driving situation OR in physical control of the vehicle, but not monitoring the driving situation, and 'on the loop' is not in physical control of the vehicle, but monitoring the driving situation. Level 3 automation induces OOTL driver state during automated driving, by design. Consequently, a key part of the driver role at this level is the smooth transition in and out of the loops of control in accordance with the different driving modes. Therefore, in order to ensure safe use of these systems, drivers need to understand what level of SA and attention they should have in relation to different modes of automation and how they need to interact with the system to calibrate their SA and attention in a timely manner during dynamic operations (Carsten and Martens, 2019).

Previous studies (e.g. Dogan et al., 2017), have highlighted performance challenges associated with the re-engagement of drivers' cognitive and perceptual-motor controls necessary to effectively takeover the driving task. For example, a recent longitudinal study (Large et al, 2019) asked drivers to spend a week using a simulated level 3 vehicle for a daily commute. Drivers were given agency over their use of personal non-driving related tasks (NDRTs), during automated driving. Results showed evidence of drivers adopting learning strategies that improved their ability to take over the operational controls of the vehicle. However, the time and effort drivers directed towards maintaining or rebuilding SA reduced. Instead, drivers increasingly prioritised engagement with their NDRT. These findings suggest that drivers appear to recognise the need to physically prepare to drive during the transition period, but not the requirement to cognitively get their mind back on the road, suggesting that if or, arguably, when a level 3 system issues a take-over request (TOR), the driver may not be ready to drive.

Behavioural adaptations (BA) are influenced by drivers' knowledge and understanding of the functionality, capability and limitations of the automated systems – their 'mental model'. BA observed in the aforementioned Large et al. (2019) study suggests that these drivers lacked a comprehensive understanding of their shared control requirements during the transition to manual control. Incomplete or inaccurate mental models have been shown to have a detrimental effect on driver behaviour (Beggiato and Krems, 2013). Therefore, it is posited that future AV training should be designed not only to improve drivers' knowledge of system capabilities and limitations, but also to motivate and guide required driver behaviours through the use of clearly defined, essential operating procedures.

Research concerning BA echoes previous lessons from aviation (Degani and Wiener, 1997), which emphasise the integral role standard operating procedures (SOPs) play in ensuring successful operations in complex human-machine systems. SOPs provide a way to standardise and specify the way required tasks should be carried out. They give clear instruction to the human operator to ensure tasks are executed in an optimal, logical, safe and predictable way. A well designed SOP should optimise the sequencing of tasks and promote efficient scheduling by the human operator. In the context of transitions of control (TOC), the SOP should arguably include sequencing tasks associated with getting the driver 'on-the-loop' of control at the tactical and strategic task levels, before taking physical control of the vehicle. Additionally, research findings on BA suggest there is also a need to inform drivers about the effects of automation on their own behaviour and the potential consequences of being OOTL to support safe interactions between the human driver and the automated systems (Carsten and Martens, 2019; Casner and Hutchins, 2019; Merat et al., 2019).

The concept of 'shared control' is often used to reflect the cooperative requirements of the driving task in AVs (Flemisch et al., 2012). This highlights the critical role that both the automation and the human driver play in the successful completion of the driving task. It draws particular attention to the importance, complexity and challenges of shared SA within a joint cognitive system that is continuously evolving. During social interactions, conversation (or "chat") is used to construct joint understanding, and facilitate efficient and effective collaboration and decision making, when working towards a shared goal. It can be argued, that, in the context of shared control during automated driving, the same underlying principles should apply. This perspective served as inspiration to develop a simple training intervention for level 3 AVs.

Aims of Study

The objective of this study was to develop and evaluate a proof-of-concept, knowledge-based, behavioural training intervention for level 3 AVs. Using behavioural change theories (Fylan, 2017) the training aimed to: improve drivers' understanding of vehicle automation; outline their role and responsibilities; and provide best practice guidance for interacting with such vehicles.

Behavioural "CHAT" training

"CHAT" was designed to build, and reinforce, an accurate mental model of level 3 AVs, and support rapid, efficient and accurate recall of required driver behaviours. The word 'CHAT' is a semantic reference to the necessary communication required whenever control is passed between members of a team. It aims to provide drivers with a memorable and semantically-relevant acronym to aid knowledge retention of both the shared control responsibility and a specific sequential order of required behaviours during a TOC. The 'CHAT' SOP is designed to encourage drivers to carry out situation monitoring prior to physically taking control of the vehicle. The expectation is that this will ameliorate the transition for drivers from OOTL to 'in-the-loop' of control, which will, in turn, support reasoned decision making for tactical or strategic driving sub tasks following a controlled takeover.

The 'CHAT' behavioural training consisted of two parts. First, it focused on ensuring drivers understand: the reasons for automation; when it is appropriate to use it; and their roles and responsibilities as a driver. Training aimed to increase knowledge and understanding of: the impact of vehicle automation on driver behaviour; the consequences associated with being OOTL; and desired ways to engage with level 3 AVs. Second, it outlined a SOP designed to support drivers in applying acquired explanatory knowledge about level 3 AVs, through a simple and efficient way of remembering a specific sequence of procedural actions. 'CHAT' instructs drivers to: CHeck 360° (*"check yourself, check for hazards, check all mirrors and check your blind-spot"*), Assess (*"assess your position, assess the road, assess the situation and assess the next step"*) and then Takeover manual control. Following an initial explanation of the CHAT procedure, a learning strategy called proactive observation (Castro et al., 2016) was used to motivate trainees to adopt the CHAT behaviours by highlighting errors that can be made during a TOC due to lack of driver situation monitoring. Trainees were presented with a bird's eye view of a takeover scenario and instructed to actively scan the road scene, applying the principles of the CHAT procedure to establish the 'Checks' and 'Assessments' they would need to make if they were the driver of the 'ego' vehicle. Expert commentary then guided them through the task, providing immediate feedback and highlighting the importance and utility of the CHAT procedure. The commentary also indirectly highlighted the consequences of *not* carrying out this procedure ahead of the takeover given spatio-temporal constraints.

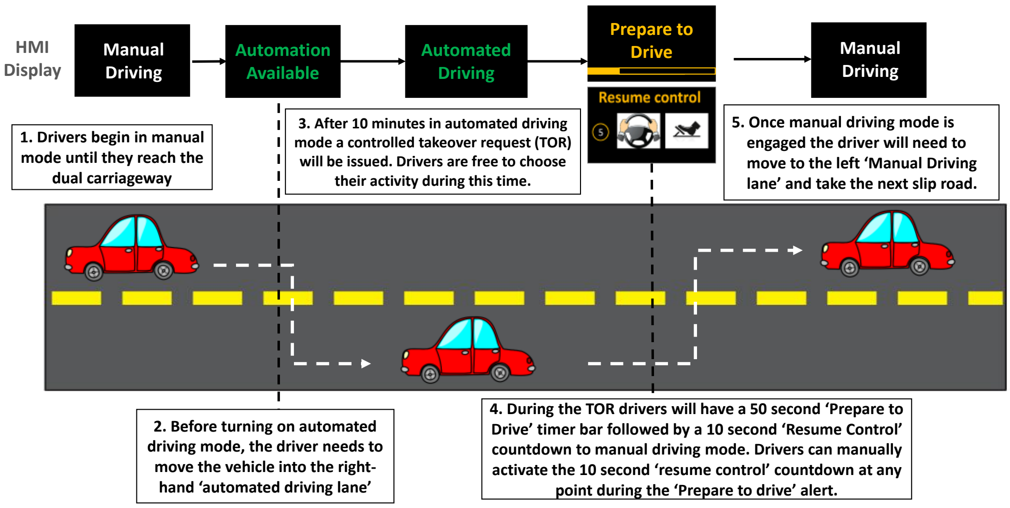

Figure 1: Schematic of experimental drive

Method

Design

A between-subjects simulator study was used to evaluate and validate 'CHAT'. The behavioural training was compared to 'operational' (user manual) training, typically provided with new vehicle technologies. The operational manual detailed the automated features fitted in the vehicle, and the capabilities and limitations of each feature, including advisory notices regarding driver engagement requirements. Both training approaches lasted for 15 minutes and were self-administered either by moving through a PowerPoint presentation (narrated by a professional actor) (Behavioural) or reading a Word document (Operational).

Participants

Twenty-four participants (19 male, 5 female; mean age: 35 years, SD: 10.06) took part in the study. All participants were experienced drivers, comprised of university staff and students. Eleven received Behavioural training and the remainder (n=13) Operational training prior to the simulated drive. Participants were recruited via advertisements on the university campus or via email, and compensated £10 in shopping vouchers. They were asked to bring to the study any activities they might use in a level 3 AV and were given agency to use these as desired during the drive.

Materials

The study took place in a medium-fidelity, fixed-base driving simulator, modified to mimic a highly-automated car. A curved screen in front of the Audi TT car and three overhead HD projectors provided a 270 degree forward and side image of the driving scene. A 55-inch curved LED television positioned behind the vehicle was used as a rear mirror and two 7-inch LCD screens were used as side 'mirrors'. The driving scenario was created using STISIM Drive (v3) software. The in-car human machine interface (HMI) was created using Microsoft PowerPoint (controlled remotely) and displayed on a 12-inch tablet positioned in the centre console of the vehicle.

Procedure

Full details of the experimental drive are in the schematic in Figure 1. Drivers were briefed on the overview of the automation and the timings and display text on the in-car HMI (see Figure 1). They were instructed that to engage automation, they needed to be in the right-hand lane of the UK 2-lane dual carriageway (lane 2) and that, following a TOR, as part of a planned takeover, they needed to resume manual control, move into the left-hand lane (lane 1) and take the next available exit. Drivers were given a practice drive to transition to and from automated driving mode, including the required lane changes. Following the takeover, drivers were required to negotiate with other road users to move into lane 1 before exiting the road. To increase face validity, the driving scenario was designed to provide a dynamic feature that could be used to assess the visual attention of drivers during the planned TOC: at the point that the TOR was issued, a blue car accelerated in the same lane as the ego vehicle, temporarily driving in close proximity to its rear ("tailgating") and then dropped back to sit at a comfortable timed headway to the ego vehicle at the point of manual mode engagement.

Data Analysis

Behaviour Observation Research Interactive Software (BORIS) (Version 7.4.7) (Friard and Gamba, 2016) was used to conduct frame-by-frame coding of behavioural observations from split-screen video recordings of the experimental drive. Cameras were positioned so that the internal and external environment could be observed. Behavioural measures included, for example, eye glance direction and frequency (to mirrors, external and internal sources), engagement with NDRT, and feet or body adjustments. Participants completed the Total Trust in Automation Questionnaire (TTAQ) (Gold et al., 2015) twice, firstly prior to the driver training and secondly following the experimental drive. In addition, participants completed the Situational Awareness Rating technique (SART) scale (Taylor, 2017) and the NASA-TLX workload questionnaire (Hart and Staveland, 1988).

Results

Results and analysis are presented on driver's subjective responses and visual behaviour during 3 episodes: automated driving; the transition of control (TOC), defined as the point between the TOR and manual mode engagement; and the lane change manoeuvre post transition. Differences between drivers receiving Behavioural training and those receiving Operational training were tested for statistical significance using unpaired-samples *t*-tests. Differences between categorical data were analysed using Fisher's exact test. Pre and post TTAQ ratings within group were analysed using paired sample t-tests.

Mirror checks and awareness of the hazard car

Results showed that the behavioural group carried out significantly more mirror checks than the operational group during both automated driving and TOC ($t(22) = 2.52$, $p = .02$; $t(22) = 3.57$, $p = .002$, respectively). On average, the behavioural group made 37.8 mirror checks during automated driving and 9.2 during the transition period, compared to 15.8 and 1.0, respectively, by the Operational group. In addition, the former group were statistically more likely to make at least one mirror glance during the TOC ($p = .005$) and significantly more drivers from this group saw the tailgating blue vehicle, compared to the Operational group (n= 10 and 3, respectively; $p = .002$).

Shared attention

Shared attention was defined as the time between the drivers' first driving-related glance (e.g. at the roadway or to a mirror) following the TOR and their final interaction associated with their NDRT. Results show that the behavioural group spent significantly less time sharing their attention during the transition period than the operational group ($t(19) = 3.92$, $p < .005$) (see Figure 2). On average, the former shared attention for 1.8 sec, compared to 11.2 sec for the latter. Additionally, the time to first roadway glance following the TOR was significantly less for the behavioural group in comparison to the Operational group (mean: 7.3 and 21.3 sec respectively; $t(12) = 2.97$, $p < .005$).

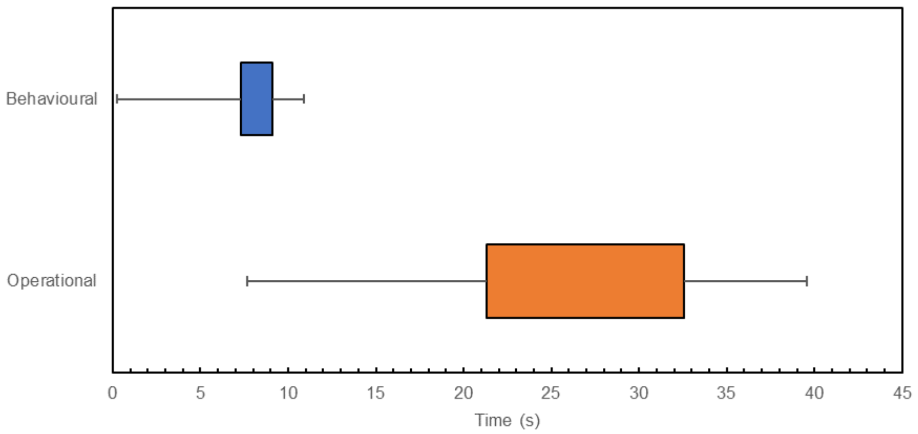

Figure 2: Initiation and duration of shared attention during TOC showing first driving-related glance to final NDRT-related glance. Mean values with standard deviation error bars.

Visual behaviour after resuming manual driving

Post takeover mirror glances were analysed and attributed to either rebuilding SA or specifically related to the lane change (LCMG). The latter were defined as those which immediately preceded or accompanied drivers' physical actions associated with manoeuvring their vehicle (e.g., moving to activate the indicator). There was no significant difference in the time taken to make the first LCMG post-takeover (p = .74) nor the time taken to physically manoeuvre the vehicle once this action was started (p = .36). However, the time between the first LCMG and the start of the physical manoeuvre of the vehicle was significantly longer for drivers in the behavioural group than the operational group (t(18) = 1.91, p = .04), (mean: 4.2-sec and 2.3-sec, respectively). The behavioural group also made significantly more mirror glances between the PTD alert and initiation of the physical manoeuvre and during the manoeuvre itself (defined as between the first LCMG or indication (whichever came first) and the end of the physical manoeuvre) ($t(21) = 3.86$, $p <$ .005; $t(21) = 2.37$, p = .012) (see Figure 3) and were significantly more likely to make multiple glances to their mirrors during the lane change (p = .016).

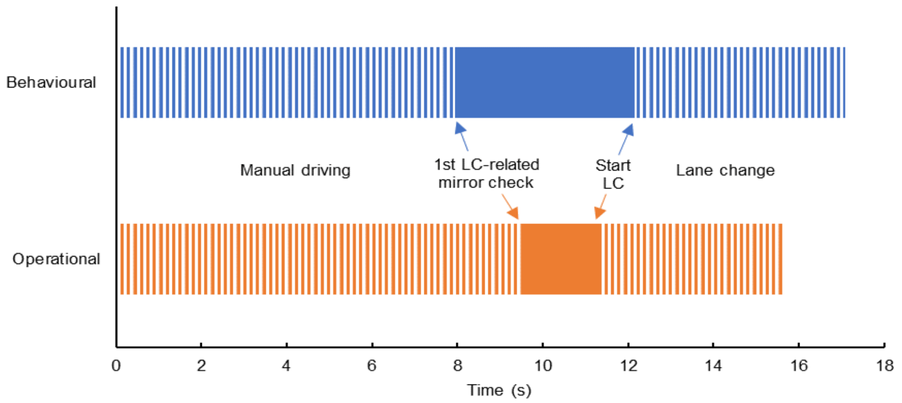

Figure 3: Time to contemplate and undertake lane-change (LC) manoeuvre (mean values). Time zero represents the start of manual driving.

Subjective Measures

The TTAQ (Gold et al., 2015) comprises five sub-scales relating to: the discharge of the driver due to automation, safety gains, safety hazards, trust in automation, and intention to use. Total trust was calculated as a cumulative score from the subscales. Pre-training ratings were comparable between groups (Behavioural and Operational). However, for pre and post ratings, there was a significant increase in 'total trust' ($t(12) = 2.75$, $p = .02$), 'intention to use automation' ($t(12) = 2.50$, $p = .03$) and 'trust in automation' ($t(12) = 3.71$, $p = .003$) within the Operational group. There were no significant differences between pre and post ratings made by drivers in the Behavioural group. The Situational Awareness Rating Scale (SART) (Taylor, 2017) explores respondents' perception of the attentional demand, attentional supply, and their understanding of the situation. Although ratings made by drivers in the Behavioural group were generally higher based on the responses captured during the study, the differences between groups were not statistically significant ($p = .097$). There were no significant differences between groups for any of the subscales. The NASA-TLX workload index (Hart and Staveland, 1988) is a multi-dimensional scale exploring mental demand, physical demand, temporal demand, effort, performance, and frustration levels. Although Total Workload (the numerical summation of all subscales, with ratings for performance reverse-scored) was statistically comparable between groups, those receiving Behavioural training indicated significantly higher temporal demand ($t(22) = 2.09$, $p = .048$), suggesting they felt greater time pressure due to the pace at which the tasks or task elements occurred, compared to drivers in the Operational group.

Discussion

The aim of the simulator study was to evaluate and validate the behavioural training by comparing it with a more traditional, operating manual, training approach. Results of mirror glance behaviour suggest that behavioural training had a positive influence on tactical level task performance during automated driving and subsequent transition to manual control. The study's findings suggest immediate, quantifiable benefits from behavioural training with the greatest positive impact on visual behaviour, supporting establishment of a proof-of-concept relating to this proposed training approach.

A notable problem highlighted in the longitudinal study by Large et al, 2019 was that drivers remained actively engaged with their NDRTs after receiving a TOR instead of preparing to drive. In the current study, we therefore explored this as a period of shared attention, defined as the time from the driver's first driving-related glance (e.g. to a mirror or the forward road scene) immediately after the TOR was issued, until their final NDRT-related glance or interaction. Not only did drivers receiving Behavioural training demonstrate an earlier, shorter period of shared attention, compared to those receiving Operational training, they also started to re-familiarise themselves with the driving scene, and completely discharge their NDRTs much sooner.

Attendance to an NDRT (including thought, i.e. 'mind not on driving') during automated driving induces an OOTL driver state (Merat et al., 2019). It could be argued that without appropriate training to improve SA in a timely way, there is a residual impact on driver SA and vigilance well after explicit shared control has visibly ceased. For example, the lack of mirror glances conducted by drivers from the Operational group during the transition period demonstrated a failure to observe safety critical areas of the roadway. This, in turn, negatively impacted their visual search and selective attention performance in perceiving the tail-gating car, putting them at increased risk of accidents related to inattention. In contrast, the evidence in this study suggests that drivers who received Behavioural training were 'on the loop' (Merat et al., 2019) during the transition period - actively monitoring the driving situation and attending to multiple on-road regions, which resulted in a greater number of mirror glances in relation to the basic vehicle motion control and during the planning and execution of the lane change manoeuvre.

On face value, the increase in trust-in-automation and intent to use reported by the Operational group post training, coupled with the lower temporal workload (or time pressure), associated with the demands of the task, reported when compared with the Behavioural training group could be interpreted as more favourable. However, shared control at intermediate levels of automation requires that drivers maintain responsibility of the vehicle even when the vehicle systems are notionally in control. Reduced SA and attention during automated driving mode is not necessarily unsafe, as long as the driver is able to calibrate their levels of SA and attention to accurately reflect tasks required for monitoring and active intervention in a timely manner in relation to different modes of automation during dynamic operations (Carsten and Martens, 2019). Therefore, it is important to attain (and maintain) appropriate levels of trust to avoid the pitfalls of over-relying on the technology. Additionally, achieving appropriate levels of workload, commensurate with task requirements, has been noted as a prerequisite to help drivers remain alert and maintain awareness (Young and Stanton, 2007) and is expected to support the accurate calibration of trust.

The subjective results suggest that drivers who received Operational training judged aspects of their own behaviour and performance favourably. However, we posit that the objective evidence presented in this report suggests these drivers may be forming opinions and making decisions based on limited knowledge (e.g. not knowing that they did not attend to the tailgating vehicle) or poorly constructed mental models, consequently leading to overly optimistic judgements about their own levels of SA, workload and level of trust they should place in the system. Such factors have already been highlighted as possible deleterious consequences of vehicle automation (Seppelt and Victor, 2016; Kyriakidis et al., 2019). These are exactly the elements that the Behavioural training aimed to address. Indeed, trust ratings made by drivers in the Behavioural group were unchanged after the experience.

Overall, results suggest that behavioural ‘CHAT’ training had a positive influence on tactical level task performance during automated driving and following a transition to manual control. It is also possible to infer that the early engagement in re-building situation awareness demonstrated by drivers in the behavioural group led to more informed and measured decision making in relation to the lane change manoeuvre. However, caution must be used when interpreting the success of these results. Firstly, the effect on knowledge retention and maintenance of desired behaviour has not been tested within the present study. Secondly, success of any proposed driver training intervention will depend on the willingness and compliance of drivers to complete it and the relevant bodies to facilitate, finance and regulate its development and management. These challenges make a valid case to investigate ways to integrate the key concepts used in this behavioural training intervention into a technological design solution, in particular, as the training intervention did not aim to introduce any new skills, but rather apply those that experienced drivers will already have to a specific operating procedure to support the new automated driving context. The next phase in this research will therefore focus on using the novel ‘CHAT’ procedure to inform the design and development of an HMI to support the uptake and maintenance of desired driver behaviours using the ‘CHAT’ principles. This will subsequently be evaluated alongside the behavioural training to draw conclusions on the sufficiency and necessity of each solution.

Conclusion

The results of this study have provided evidence of the necessity and potential impact of behavioural training. ‘CHAT’ offers a practical intervention that provides a way to standardise a set of sequential, procedural actions required by drivers during the transition to manual control. Due to its memorable and succinct design ‘CHAT’ offers versatility as a potential design template for HMIs and public service campaigns. However, it is important to note that this is just the starting point. A checklist on its own is not enough and does not replace knowledge, training and practice. Drivers were not only provided with a checklist to follow they were motivated to behave in a particular way due to the training they received alongside the ‘CHAT’ SOP, prior to the drive. The next step will be to further validate and test the effectiveness of the training intervention over time.

Acknowledgements

The research was conducted as a collaboration between the RAC Foundation and the University of Nottingham. The authors would like to thank Elizabeth Box, Doreen Lam and the other members of the RAC Foundation team for their valuable guidance and support. The authors would also like to thank George Telfer, actor and erstwhile driving instructor, who kindly provided voice-over narration to accompany the behavioural CHAT training.

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