Centre for Accident Research
& Road Safety - Queensland

Cooperative and Highly Automated Driving Safety (CHAD) Study

Work Package 1: Driving Task Transition in Automated Vehicles

Summary Report
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ACRONYMS

AD	Automated Driving. All driving tasks are being carried out by ADS, including steering, brake, and acceleration.
AVs	Automated Vehicles
ADS	Automated Driving System
CAVs	Cooperative Automated Vehicles
DMS	Driver Monitoring System
Handover	Act of switching from manual driving mode to automated driving mode
MD	Manual Driving. All driving tasks are being carried out by a human, including steering, brake, and acceleration.
MCoE	RACQ Mt Cotton Mobility Centre of Excellence
NDRT	Non-driving Related Task
QUT	Queensland University of Technology
SAE	Society of Automotive Engineers
SD	Standard Deviation
Takeover	Act of switching from the automated driving mode to manual driving mode
TMR	Department of Transport and Main Roads
TOT, TOR	Takeover Time, Takeover Request
WP1	Work package 1
ZOE2	Level 4 CAV prototype vehicle used for this project

1 INTRODUCTION

1.1 BRIEF BACKGROUND AND AIMS OF WORK PACKAGE 1

This document contains the summary report for Work Package 1 (WP1) of the Cooperative and Highly Automated Driving (CHAD) Safety Study. WP1 was designed to investigate public participants' experiences behind the wheel of the ZOE2 automated vehicle (AV). Specifically, participants were assigned to one of two conditions that differed by the number of planned transitions between Automated Driving (AD) and Manual Driving (MD) that were experienced in a 30 minutes' automated drive around the closed, test track at the RACQ Mt Cotton Mobility Centre of Excellence (MCoE).

Data was collected via several channels. This summary report includes the subjective data collected via Pre- and Post-drive questionnaires, and objective data collected via the ZOE2 internal sensors. Analysis investigated both between-subjects (different conditions; Low takeover request versus High takeover requests) and within-subjects (individual differences and experience over time: Pre- versus Post-drive questionnaires) factors and included assessment of several outcome measures: participants' acceptance of the AV, perceived risk of AV manoeuvres, and other experiences related to AV use, Takeover time and Handover time, first actuator used by the participants in a takeover, ZOE2 kinematic data while in manual mode, as well as eye-tracking data from the Driver Monitoring System (DMS).

The Takeover and Handover are critical in this study as they are safety related manoeuvre in the driving task. They relate respectively to the transition from the AD mode to the MD mode, and from MD mode to the AD mode. A takeover of the driving task by the driver can be planned or unplanned. The planned takeover does not relate to a safety critical manoeuvre, as it can be planned sufficiently in advance (such as the AV reaching the end of the road section where automation is permitted). However, the unplanned takeovers can create safety issue/s. It usually relates to an emergency request from the Automated Driving System (ADS) which could be in response to a complex situation it has encountered or loss of sensor input.

These tasks and associated studies are outlined in a series of unpublished reports prepared for the Department of Transport and Main Roads (TMR) including:

1. *Pascale M., Rakotonirainy A., Glaser S., WP1: Study plan, Takeover Request scenarios, Nov 2019.*
2. *Pascale M., Rakotonirainy A., Glaser S., WP1: Study plan, Safety Indicators, April 2020*
3. *Pascale M., Glaser S., Demmel S., Dehkordi S.G., Coughlan P., Rakotonirainy A., WP1: Technical report, Scenario implementation and validation, Jan 2021*
4. *Pascale M., Glaser S., Demmel S., Schramm A., Coughlan P., WP1: Technical report, test report, April 2021*
5. *Pascale M., Glaser S., WP1: Key findings report, Subjective study – analysis, July 2021*
6. *Pascale M., Glaser S., WP1: Key findings report, Objective study – analysis, April 2022*
7. *Watson-Brown N., Glaser S., WP1: Addendum, Safety criteria and driving performance during automated vehicle takeover, Feb 2023*

This report summarises the aforementioned series of deliverables.

1.2 HIGH LEVEL RESULTS FROM THE SUBJECTIVE AND OBJECTIVE DATA ANALYSIS

In terms of both experimental results and study outcomes, WP1 was unique. This study was one of the earliest international efforts to conduct prolonged periods of automated driving with the participation of the general public. The findings from this study have the potential to contribute significantly to the development of legislation, engineering and infrastructure for autonomous vehicles, as well as the design of supplementary systems to ensure safe AV operation.

1.2.1 SUBJECTIVE DATA

Experiments around collecting subjective data were designed to gain insights into participants' acceptance of the AV, perceived risk of AV manoeuvres, and other experiences related to AV use.

Participants reported greater acceptance after experiencing the AV. The largest changes in participants' Pre- versus Post drive responses were for stressfulness (less stress) and comfort performing a non-driving task (more comfortable). Participants also reported that the AV felt less risky after experiencing it for the 30-minute drive. The percentage change for risk was more than double the change in acceptance. Non-driving tasks (NDT) were reported to be the riskiest behaviour related to AV operation (i.e., performing a secondary task while the vehicle was in automated mode). Alongside the riskiness ratings, participants also reported that takeovers were significantly less difficult than they expected before driving the vehicle.

No differences were found between conditions with respect to acceptance or riskiness; however, participants who experienced more takeover requests (TOR) indicated that they were less aware of what the vehicle was doing than participants who experienced fewer TORs.

Participants provided written feedback on aspects of the AV that may need adjusting. The most common concerns that participants raised were related to the vehicle behaviour (braking, cornering, and speed which were described as harsh, jerky, slow, and unnatural). These comments reflect known limitations of the current driving experience which has improved as the Automated Driving System progresses within the Mt Cotton context.

1.2.2 OBJECTIVE DATA

Objective data analysis focused on driving periods that surrounded takeovers of control following takeover requests (TOR). The experiments were designed to gain insight into two key questions: 1) Within how many seconds participants took over control of the CAV following a TOR? and 2) Whether the participants exercised takeover control in a situationally aware state?

Analyses investigated vehicle data, e.g., sensors and kinematics, as well as eye-tracking data from the Driver Monitoring System (DMS). For the vehicle data, we focused on participants physical responses to takeover requests (TORs) exploring the time to retake manual control of the vehicle (takeover time [TOT]). For the eye-tracking data, we focused on participants' gaze before, during, and after TORs. Analyses were conducted to determine differences across the two experimental conditions, related to the number of takeovers that participants experienced, as well as differences due to participants' age and other demographics.

The TOTs observed in this study were similar to those reported in prior published research examining TOTs in simulator environments. Analysis suggested:

- The fastest takeovers occurred at just under three seconds.
- Slower participants took between four and five seconds, and in the worst instances, between six and seven seconds.
- There were a handful of TORs where participants simply did not take back control, however the reasons behind those decisions are unknown. A possible explanation is that the participants were curious to see what would happen.

It is important to note some limitations of WP1 study, these are:

1. Even though WP1 participants were offered an option to use their mobile devices, while the vehicle was in automated mode, most chose not to engage in non-driving tasks, such as using their mobile devices.
2. TOR warnings were communicated to the participants through audio and visual means only. No haptic alerts via seat and/or seatbelt were used.

In conclusion, we suggest, a minimum of 5-6 seconds should be allotted for safe takeover to account for the majority of drivers, even at their slowest. However, this only applies 1) if operational requirements prohibit engagement in non-driving tasks, and 2) TOR warnings are only provided through audio and visual means (no haptic alerts via seat and/or seatbelt).

We anticipate that active engagement in a non-driving task, and subsequent disengagement from the driving task will result in longer TOTs which help to define TOR requirements in instances where participants are permitted to fully disengage from the driving task[1]. Use of haptic alerts via seat and/or seatbelt during TOR have potential to reduce the overall TOT: haptic feedbacks can reduce the visual workload and convey information, such as for preventing from hazards[2]

Our analysis of the driving performance data collected during the WP1 experiments suggested:

- the first five seconds of takeover showed greater driving performance instability with more deviations from the planned trajectory, but on average, the vehicle remained within 1.75m of the trajectory in all conditions, which is within the standard width of an Australian urban lane (3.5m).

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[1] This study was further expanded utilising the Road Safety Innovation Fund (refer to Section 4 - Extension to WP1 study for preliminary results) where participants were given certain task while being seated in the driver's seat during automated mode drive.

[2] Gaffary Yoren, Lécuyer Anatole, "The Use of Haptic and Tactile Information in the Car to Improve Driving Safety: A Review of Current Technologies" Frontiers in ICT, vol 5, 2018, DOI=10.3389/fict.2018.00005

2 SUMMARY OF WP1 EXPERIMENT

2.1 ETHICS APPROVAL AND AUTOMATED VEHICLE DESCRIPTION

2.1.1 ETHICS APPROVAL

The Queensland University of Technology (QUT) Human Research Ethics Committee (UHREC) has reviewed and accepted this study under the UHREC Reference number 2021000025. The project has been accepted as "Low-risk" following the guidelines from the Standard Operating Procedures acquired earlier in 2021.

2.1.2 AUTOMATED VEHICLE

The AV proposed for the demonstration is a standard EU/UK model Renault ZOE (also, Zoé) electric car, with additional technology and modifications which allows it to operate in either normal or automated (SAE Level 4) mode.

The CAV is intended to be a research platform and has been developed to support four driving modes:

1. Normal or manual driving mode - this is consistent with commercially available vehicles without the enhanced technology.
2. Environmental recording mode - this is same as manual driving however the computers can still record the sensors signals and vehicle signals such as vehicle speed, actuators' position, and algorithms' output. The reading of vehicle data does not interfere with vehicle control.
3. Simulated mode - this is same as manual driving however the vehicle uses its own sensors or recorded signals to run the sensing and decision algorithms but without controlling the actuators such as brake, acceleration, and steering functions.
4. Automated mode - this is where the vehicle uses sensors, computers (software and hardware) and actuators to drive the AV.

The automated mode technology has five key technologies:

1. Human-machine interface,
2. Obstacle detection,
3. Localisation,
4. Connectivity, and
5. Path planning and execution.

The HMI is central in the safety protocol as it gives information about the vehicle and Automated Driving System (ADS) status. The HMI comprises the following elements:

1. Central cluster display: the screen displays information about the route and the current active mode, and audio recordings can be played as well.
2. Engineering screen (upper screen): The screen displays the environment sensed by the vehicle and several green/red lights associated with the performance of the ADS (it is principally intended for the expert driver).
3. Automated button: the button to switch into automated mode has an active led light which changes depending on the availability of the automated mode.

2.1.3 HMI DESIGN

The ADS warns the driver when the vehicle reaches a take-over point by displaying a specific graphic and playing an alarm sound. If the driver does not take control back after a short while, the vehicle stops safely on the side of the road (minimal risk manoeuvre).

TORs were displayed on the HMI in the centre of the dashboard. For TORs from MD to AD, the AD on/off button on the central console to the right of the screen also flashed green

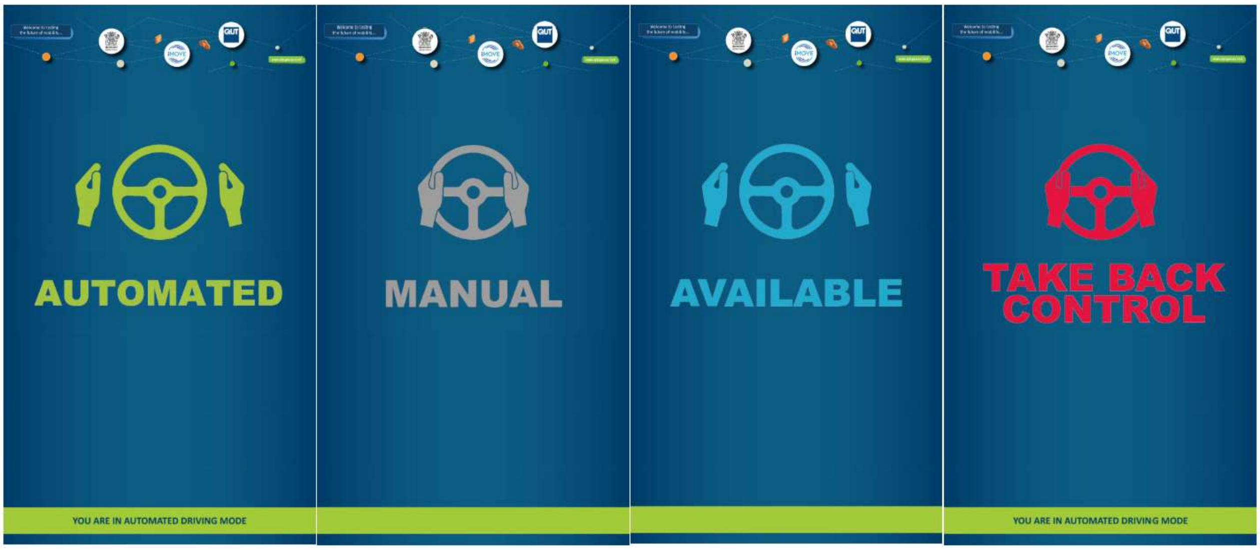


Figure 1 In-vehicle images displayed on the HMI to indicate the current driving mode (left and centre-left), and also when a transition was suggested

A limitation to this study relates to the handover process: the driver must align the vehicle with the planned trajectory (within certain boundaries) to engage the Automated Driving. This process may create distraction and lower performance of the driver. The training process was deemed to minimise this burden on the driving task. Commercial vehicles, in the future, will certainly have a more friendly process to engage the automated mode.

2.2 STUDY DESIGN

2.2.1 PARTICIPANTS AND DEMOGRAPHICS

Participants (n = 73, 21 females/ 52 males, Mean age = 46.66, Standard Deviation age = 15.78) were recruited via social media and local news bulletins. All public participants were volunteers living in the greater Brisbane area who hold a valid driver's licence; and all public participants received a $100 gift voucher for completing all tasks. All participants were randomly assigned to one of the two conditions when they arrived on site: 'High' likelihood of takeovers (n = 37) versus 'Low' likelihood of takeovers (n = 36).

Table 1 Participants' demographics

	Mean	St. Dev.	Min	Max
Number of years with licence (years)	28.52	15.12	3.00	60.00
Self-reported safety while driving: Not safe (0) to very safe (100)	79.33	12.90	50.00	100.00
Knowledge of AV: Limited (0) to full (100) knowledge	39.49	25.08	0.00	84.00
Experience with automation: None (0) to partial automation (50) to full automation (100)	35.32	30.41	0.00	100.00
Technology readiness (mean): Low readiness (0) to high readiness (100)	66.99	16.65	29.25	100.00

2.2.2 PARTICIPANTS EXPERIENCE

Participants arrived at the RACQ Mt Cotton Mobility Centre of Excellence (MCoE) and followed the timeline of events in Figure 2. Each participant began in the office area to complete consent and desk training (short video instruction), which included the pre-experience questionnaire. Next, they completed a short training session in the vehicle (< 5 minutes) to show them how to manage transitions of control. They then experienced automated driving for the 30 minutes according to their allocated condition (High or Low). After the experimental drive was finished, the participants went back to the office area to complete the post experience questionnaire.

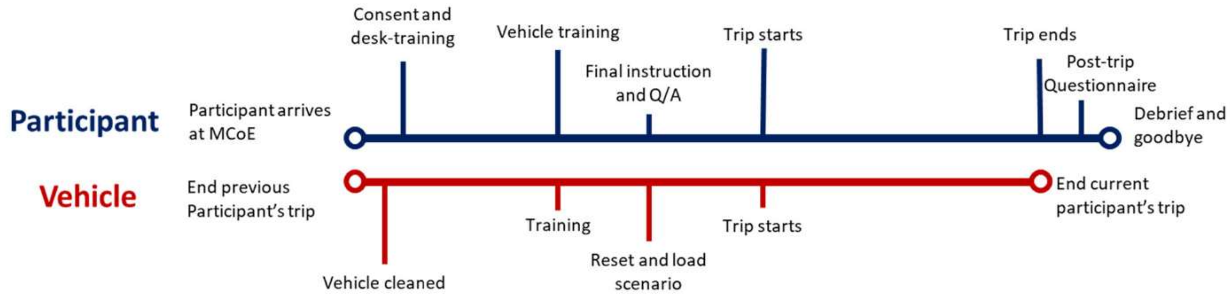


Figure 2 Timeline for participant and vehicle

2.2.3 LAP DESIGN, AND TAKEOVER REQUEST POSITIONS

All driving for WP1 was completed at the RACQ Mt Cotton Mobility Centre of Excellence (MCoE). The MCoE has two tracks (the Large Vehicle Manoeuvring Area (LVMA) and the road circuit) that were hired each day. The complete drive was broken down into seven “laps” around the combined tracks. The map recorded by the AV, which includes all laps, can be seen in Figure 3. On some laps, depending on the participant’s allocated high or low condition, a takeover request (TOR) from automated driving (AD) to manual driving (MD) was issued via the HMI. Following a successful takeover, within 1 km of every TOR, AD became available again so that the participant (driver) could re-engage AD mode. The goal was to create a continuous driving experience that was predetermined but unpredictable (from the participant’s perspective), and to have two different scenarios, where takeovers occurred frequently (five takeovers in seven laps) or infrequently (one takeover in seven laps). Each participant also experiences a TOR at the very end of the experience.

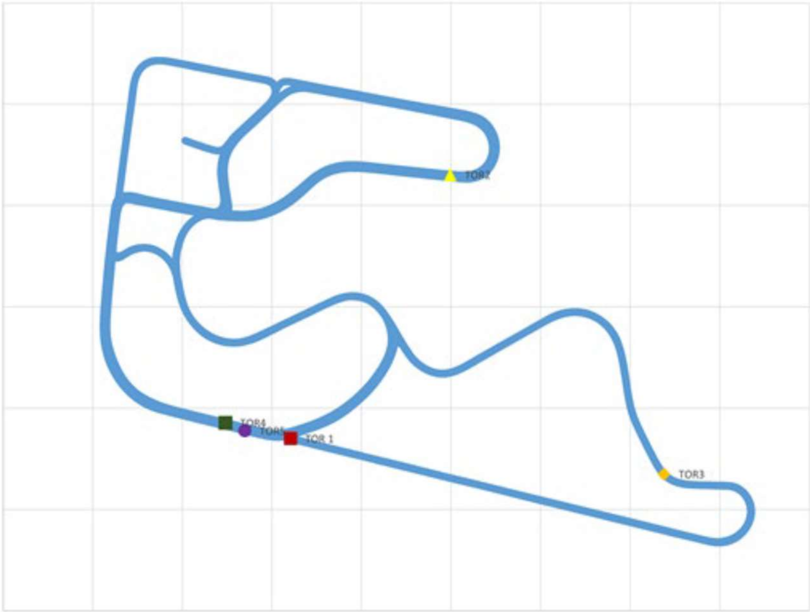


Figure 3 Lap description for Low and High condition.

2.3 FINDINGS FOR SUBJECTIVE DATA ANALYSIS

2.3.1 ACCEPTANCE

The acceptance data suggest that driving in the AV was a positive experience regardless of the number of takeovers. Considering that this experience would be a first for most participants, this is not a surprising result. Additionally, the data suggest that participants who consider themselves to be high in technology readiness (early adopters and those who integrate technology into their daily lives more regularly) similarly reported higher acceptance ratings.

Moving forward, the acceptance data suggest that further research is needed on the impact of takeovers. Potential future studies include increasing the number of takeovers further in the high takeover condition, changing the impact of takeovers on the driving experience, extending the duration of the experience to introduce longer gaps and increase boredom, introducing complex secondary tasks that require undivided attention, among others.

2.3.2 PERCEIVED RISK

The risk data suggest that driving an AV reduces perceived risk towards AVs. Considering the novelty of this experience for participants it is not surprising that they potentially overestimated the riskiness of driving in an AV at first. It is also notable that the percentage difference between pre-drive and post-drive questionnaires was more than double that of acceptance. This may suggest that the risk associated with AV-use is less understood in the public-eye, and that short first-hand experiences can have significant impact on perceptions of the technology. Another notable outcome was the difference detected as the number of years with a licence increased; as years of driving increased, the predicted riskiness ratings decrease, suggesting that drivers with more experience found the vehicle to be operating in a less risky way. Note that participant age was not a significant factor in this analysis.

2.3.3 TRANSITION AND SYSTEM TRANSPARENCY

For all participants, the expected difficulty of performing takeovers was significantly reduced after driving the vehicle. With respect to system transparency, however, differences between conditions emerged. Participants in the High-takeovers condition reported a slight decrease in their expectations of system transparency, compared to participants in the Low-takeovers condition who reported a slight increase in system transparency. It would seem, therefore, that experiencing more unexpected (from the participant's perspective) takeovers has a slight negative effect on participants interactions with the AV system, even though they still reported higher acceptance, and lower perceived risk, after driving in the vehicle. No warning, besides the takeover request, was provided to participants, who were therefore unable to understand why the takeovers were occurring.

2.3.4 QUALITATIVE FEEDBACKS

The follow-up question gave participants space to provide more context (free response) around their selections. Using all responses, a word cloud (Figure 4) was generated showing the top thirty descriptive words. To build this word cloud a set of words was excluded that had little meaning out of context, such as "system" or "pull" or "need". It is clear that participants provided the most feedback on braking, cornering, speed (including 'slow' speeds), and the smoothness of the driving experience.

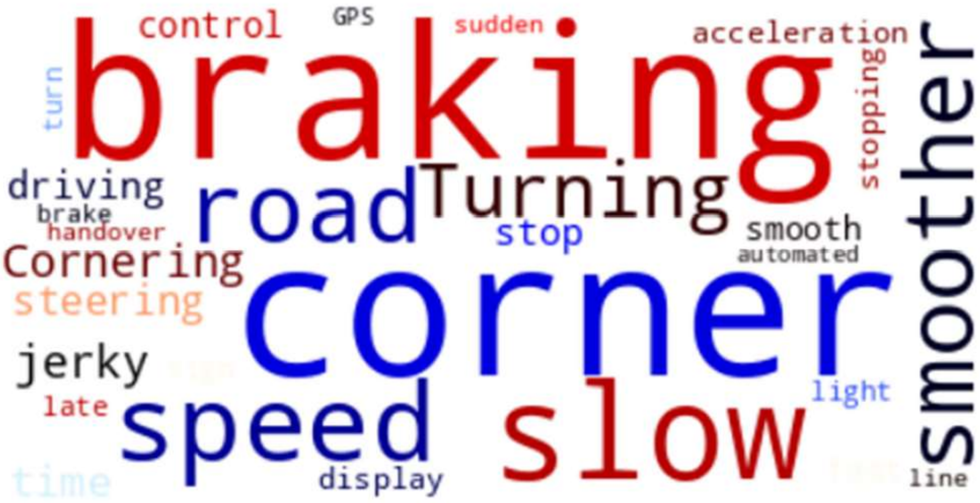


Figure 4 Word cloud generated from open question

2.4 FINDINGS FOR OBJECTIVE DATA ANALYSIS

2.4.1 TAKEOVER TIME

The primary analysis for WP1 was participants' TOTs in response to TORs. The study was designed to investigate how the number of takeovers participants experienced affected their ability to take back control of the vehicle from automated mode. The analyses, therefore, focused on the response time to a TOR, i.e., the TOT, as well as physical characteristics of the takeover and other demographic factors that may influence TOT.

Table 2 Takeover time, in seconds, for each planned TOR (including mean, standard deviation (SD), min and max)

TOR (Condition)	Mean (SD)	Min	Max
First (Low)	3.92 (1.58)	1.39	8.71
First (High)	3.49 (1.08)	1.96	6.99
Second (High)	2.86 (1.20)	1.75	6.79
Third (High)	2.80 (0.94)	1.68	6.14
Fourth (High)	2.67 (0.78)	1.39	5.12
Fifth (High)	2.87 (0.78)	1.73	5.44

The TOT data were analysed using a mixed effects generalised linear model (GLM), with the data modelled as a gamma distribution (to account for skewness and kurtosis). Mixed effects GLM was the best choice to account for the fixed effects, i.e., differences between condition or age, as well as the random effects, i.e., individual differences in participants. To further increase the quality of the model, robust standard errors were used, which reduce the effects of potentially irregular data points. Results suggest that participants' mean TOT in the High condition were faster than participants' TOT for the first TOR in the Low condition.

The number of takeovers experienced in total, directly affected TOT indicating that participants who experienced more takeovers had faster TOTs. One explanation for this outcome is that unplanned takeovers elicited less trust in the vehicle, which may have limited participants' willingness to engage in an NDRT thereby reducing their disengagement from the driving task. Alternatively, participants who experienced more planned TORs gained skill and completed the takeover faster. Keep in mind, however, that the difference in TOT was less than one second, which had no impact in the current context.

When age was explored as a factor, older adults tended to respond slower to the first TOR, but their average TOR for all takeovers (High condition) was not different from younger drivers. These data suggest that older drivers, initially, either responded slower deliberately- exercising increased caution, or simply because reaction time tends to slow as age increases.

2.4.2 DRIVER MONITORING SYSTEM AND AREAS OF INTEREST

The DMS collected eye tracking data each participant's entire drive. The DMS was initially set up to measure gaze towards several areas of interest (AOIs) which were the road ahead, the centre dashboard (HMI), the engineering screen, the instrument cluster, the rear- and side-view mirrors, and the driver's lap (**Error! Reference source not found.**).

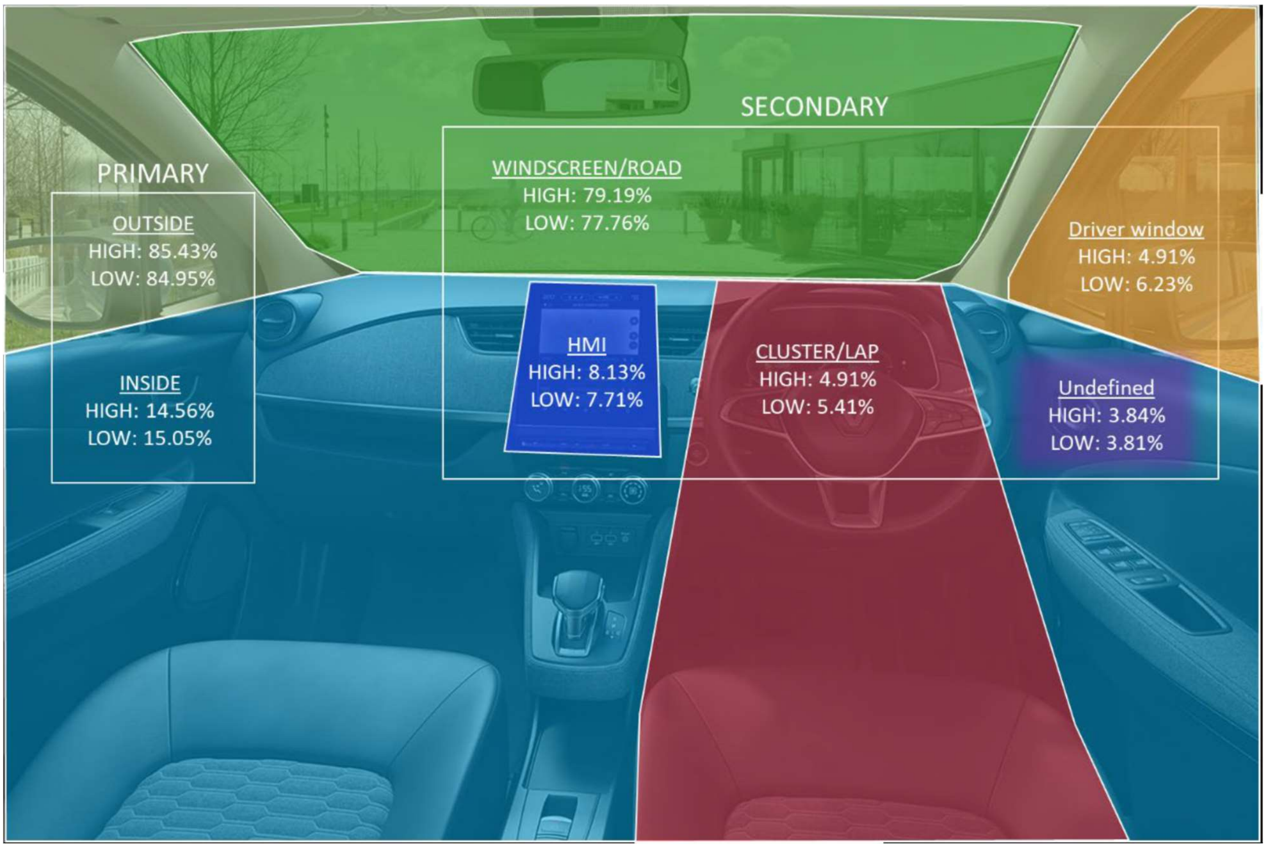


Figure 5 Primary and secondary driver gaze location during the takeover for each condition

Although, participants were offered an option to use their mobile devices while the vehicle was in automated mode, most chose not to. Limited disengagement from the driving task was supported by gaze behaviour which suggested that participants remained engaged with the vehicle's navigation while it operated in automated mode (gaze directed through the windscreen, through the window, or towards the HMI). This may be the result of the experience being novel and exciting, or potentially because of the unexpected number of unplanned takeovers that may have limited overall trust in the vehicle's operation.

As with TOTs, there were limited differences in gaze behaviour between participants in the High and Low conditions; however, there were more pronounced differences when the fastest versus slowest takeovers were compared, as well as differences when age was taken into consideration. Specifically, gaze directed towards the road was not always indicative of faster TOTs. The fastest TOTs were correlated with gaze directed towards the HMI and less gaze directed towards the area defined as cluster/lap which we operationalised as non-driving task behaviour. This was detected primarily for middle aged adults who tended to direct their gaze away from the road more often than younger or older adults, but who still had faster TOTs, on average. Older adults, who spent most of the time looking towards the road, tended to have the slowest TOTs.

Together these data suggest that experiencing the High or Low number of planned takeovers did not have an impact on gaze before, during or after takeover behaviour. There are several possible explanations for this outcome. First, participants did not have a forced task[3] to complete while the vehicle was in automated

[3] This study was further expanded utilising the Road Safety Innovation Fund (refer to Section 4 -Extension to WP1 study for preliminary results) where participants were given certain task while being seated in the driver's seat during automated mode drive.

mode, and although instructed not to, many participants engaged in conversation with the expert driver. Given that gaze was directed outside the vehicle most of the time, we can posit that participants remained mostly engaged with the vehicle's automated-driving behaviour rather than engaging in a self-directed non-driving task, like using their mobile phone. A second explanation is that the number of unplanned takeovers similarly reduced participants willingness to engage in a task that would draw their attention away from the driving task. Additionally, as it was all participants first time operating an AV, it was further unlikely that they would engage in some form of distraction from the vehicle's behaviour which was novel and exciting.

2.4.3 Driving performance

Vehicle measures are reliable sources of information that are valid behavioural indicators of safety. Examples include gap-acceptance, headway, and major lane deviations. However, there is no consensus regarding the criterion that defines competent driving performance. A literature review determined the performance measures. They were used to assess driving performance during the takeover from automated to manual mode and return to automated mode in a CAV. The first surrogate measure to driving performance is the time spent in manual driving: as participants were instructed to engage Automated Driving after a takeover, this demonstrates their capability to control the vehicle close to planned path displayed by the ADS. Handover time in the table below does not show statistical differences between individual takeovers and between the two conditions.

Table 3 Comparison between high and low takeover groups on handover time, frequency of deviations and magnitude of deviations

	TOR 1 (low) Mean (SD)	TOR 1 (high) Mean (SD)	TOR 2	TOR 3	TOR 4	TOR 5
Sample size	29	32	32	30	30	28
Handover time (secs)	25.06 (22.21)	20.99 (4.91)	21.09 (11.16)	29.05 (11.36)	26.56 (9.52)	31.84 (27.56)
Frequency of deviations*	.14 (.05)	.15 (.06)	.12 (.07)	.17 (.05)	.11 (.05)	.14 (.06)
Magnitude of deviations	0.73 (.36)	0.79 (.75)	1.39 (.83)	1.03 (.27)	0.83 (.82)	1.10 (1.01)

The frequency of deviations from the trajectory shows mixed findings. In an examination of the means, TOR 4 had a lower mean than TOR 1 from the low TOR group. This suggests that there are fewer deviations from the trajectory when a participant has experienced more than one TOR. Whereas the mean frequency of deviation doesn't have significant discrepancies.

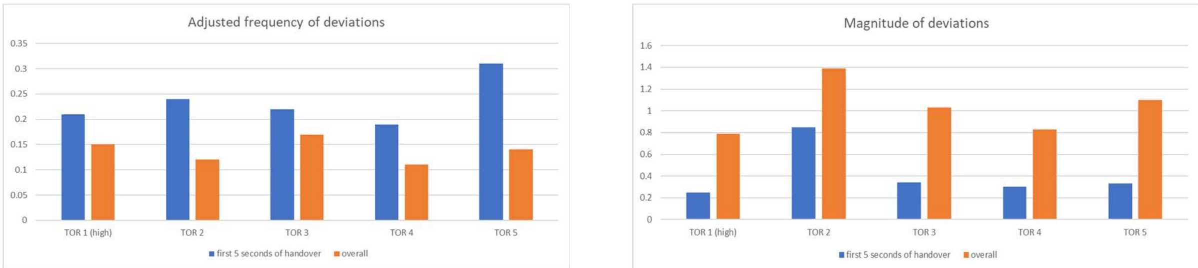


Figure 6 comparison of overall frequency of deviations and magnitude of deviations for the five first seconds and during the whole manual driving

Comparing these variables during the manual driving and at the beginning of the TOR demonstrates significant discrepancies: Magnitude of deviations are significantly smaller, but needs to be reconciliated with the duration (5 seconds versus more than 20 sec). The frequency of deviation from the planned trajectory reflects greater driving performance instability in the first five seconds.

The above data analysis suggest that the participants demonstrate lower performance at the very beginning of the takeover as evidenced by the higher number of steering angle variation (frequency of deviation) in the first five seconds rather than on the whole manual driving. But the drivers remain, as an average, within the lane boundary (magnitude of deviation around 0.8m maximum).

Other findings of the analysis include:

- The test track environment, and the ZOE2, allow for the measurement of longitudinal and lateral acceleration outside of a driving simulator, providing a unique research opportunity.
- Limited studies have examined or reported driving performance thresholds. This study provides an opportunity to determine acceptable driving performance standards in future research.
- The minimal significant differences on the performance measures between takeover requests, including low and high groups, suggests no learning effect from repetitive takeover requests.

3 CONCLUSION OF WP1

The current study sets a foundation for future studies exploring driver behaviour in the ZOE2, however some technical aspects of vehicle operation at the RACQ Mobility Centre have impacted the experiments and are since mostly resolved (e.g., GPS signal loss and fake obstacles).

3.1 SUBJECTIVE STUDY CONCLUSION

- Participants have rated their AV experience as "positive" regardless of the number of takeovers.
- Following an AV experience participant's perceived risk of AV reduced, participants initially overestimated their perceived risk. This perceived risk improvement was observed on all age groups. Moreover, participants with more years with a driving licence (Driving Experience) found the AV experience to be less risky.
- All participants' expected difficulty of performing takeovers was significantly reduced after the AV experience. Between the high condition and low condition cohorts, participants in the high condition showed a slight negative effect on the interaction with the AV.
- The biggest concerns (and therefore most desirable changes) were related to speed and ‘smoothness’ while cornering, ‘smoothness’ when slowing down or coming to a stop, and general speed while traveling.
- Results also demonstrate the limitations of the experiment, where further factors need to be investigated such as longer experience to generate boredom, inclusion of complex secondary task or transparency in the alert before the takeover request, paving the way for further experiments.

3.2 OBJECTIVE STUDY CONCLUSION

- TOTs approximated those described in previous research investigating TOTs in simulators. The fastest takeovers occurred just under three seconds; however, some participants were slower taking longer than four seconds, and in the worst instances, between six and seven seconds. There were a handful of TORs where participants simply did not take back control, however the reasons behind those decisions are unknown. We suggest, a minimum of 5-6 seconds should be allotted for safe takeover to account for the majority of drivers, even at their slowest. However, this only applies: 1) if operational requirements prohibit engagement in non-driving tasks, and 2) TOR warnings are only provided through audio and visual means (no haptic alerts via seat and/or seatbelt).
- Further exploration is necessary to understand the impact of complex non-driving tasks on TOT. The gaze behaviour suggest that participants remained engaged with the vehicle’s navigation while it operated in automated mode. This may be the result of the experience being novel and exciting, or potentially because of the unexpected number of unplanned takeovers that may have limited overall trust in the vehicle’s operation. In any case, we anticipate that active engagement in a non-driving task, and subsequent disengagement from the driving task will result in longer TOTs which will require a different TOT allotment.
- The simple “take back control now” message was effective at alerting drivers to TORs in the current context, however, as above, participants were not engaged in a distracting non-driving task.

Further testing on multimodal TORs using more advanced images, audio, haptic alerts via seat and/or seatbelt may contribute to faster TOTs. Additionally, advanced TORs can be used to convey urgency which may be useful if TORs occur suddenly, with reduced timeframes.

- The throttle was used most often to take back control of the vehicle however no clear option was best. Under more constrained circumstances (i.e., when engaged in a difficult non-driving task), or with more complex takeover scenarios (e.g., traffic situations where maintaining the current travel speed is not appropriate), the best course of action(s) for taking back control will inevitably be different.
- As with TOTs, there were limited differences in gaze behaviour between participants in the High and Low conditions; however, there were more pronounced differences when the fastest versus slowest takeovers were compared, as well as differences when age was taken into consideration. Specifically, gaze directed towards the road was not always indicative of faster TOTs. The fastest TOTs were correlated with more gaze directed towards the HMI and less gaze directed towards the area defined as cluster/lap. This was detected primarily for middle aged adults who tended to glance off-road more often but have faster TOTs. Older adults, who spent most of the time looking towards the road tended to have the slowest TOTs.
- The test track environment provides a rare opportunity to measure longitudinal and lateral acceleration outside of the driving simulator setting. As limited studies have examined or reported driving performance thresholds. This study provides an opportunity to determine acceptable driving performance standards in future research.
- The minimal significant differences on the performance measures between takeover requests, including low and high groups, suggests no learning effect from repetitive takeover requests, from the performance measure perspective, and the first five seconds of takeover reflected greater driving performance instability via a higher frequency of deviations from the planned trajectory compared to the overall handover time. However, in all conditions, on average, the vehicle (under human control) remained within 1.75m in reference to the trajectory (the standard width of an Australian urban lane).

4 EXTENSION TO WP1 STUDY

From the identified limitation of WP1 study, future studies have started investigating:

1. How TOTs are affected when participants are engaged in tasks while the vehicle is operating in automated mode.
2. How the transparency of automated driving information impacts the TOTs,
3. How the participants react to the TOR due to physical activities on the road (such as roadworks) and its impact on the TOTs
4. How specific cohorts react to the AV.

These future studies will utilise the base experiments and associated software/tools developed by the WP1. The research questions underlying the above points 1 to 3 have been funded by a Road Safety Innovation Fund, led by Dr Sebastien Demmel, while the point 4 is currently under investigation by Prof Joanne Wood for the older driver through an iMOVE project.

At the time of publishing this report, interim results for the first two points from the RSIF project are available as detailed in the following sections.

4.1 ROAD SAFETY INNOVATION FUND (RSIF)

4.1.1 RSIF STUDY 1, SUMMARY

Study 1 looked at how the driver of a conditionally automated vehicle (SAE J3016 Level 3) performed when asked to takeover (Takeover request, TOR) depending on different level of non-driving tasks (NDT).

Participants were assigned to two NDT load conditions, the High condition and the Low condition. In both conditions they were watching a 30 minutes-long video[4] on a tablet and were asked to complete a questionnaire related to the video at the same time. This setup could be representative of a work-like task in a future conditional AV. In the Low condition the questionnaire was very short with only 2 questions, while the High conditions there were 21 questions. The questions were out of order and the video was slightly longer than the total time spent in automated mode, so completing all questions would have required additional effort.

The ZOE2's HMI was the same in both conditions, with no specific system transparency mechanism. A graphic would display the current mode (manual driving, automated driving) and at pre-defined locations a TOR would be triggered, and specific flashing graphics displayed while an alert chime would play until the participant took control. Refer to Figure 7 for the graphics.

If the participant did not react, ZOE2 would automatically slowdown and stop and remain stopped until disengaged by the participant or the safety driver.

[4] The video was "GOING SUPERSONIC with U.S. Air Force Thunderbirds! Pulling 7 G's in an F-16 -Smarter Every Day 235" by the youtuber SmarterEveryDay (https://www.youtube.com/watch?v=p1PgNbgWSyY)

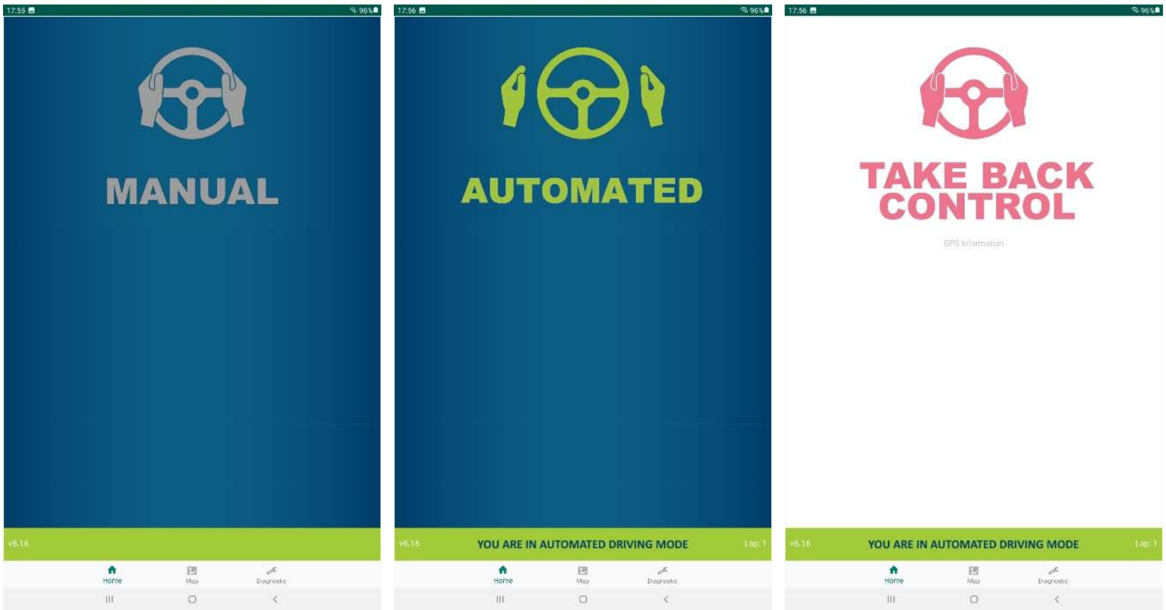


Figure 7: HMI view for study 1; manual (left), automated (centre), TOR (right)

The mean measured takeover time (TOT) was 6.13 seconds (SD = 3.51 s) in the High condition and 4.88 seconds (SD 3.0 s) in the Low condition (Figure 8). Detailed results are shown in Table 4. These results remain similar if TOT measurements above 10 seconds are excluded.

Table 4: statistics for TOT by condition (study 1)

Condition	Mean	SD	Median	Min	Max
High	6.13	3.51	4.98	2.05	19.17
Low	4.88	3.00	3.80	2.30	19.37
Both	5.53	3.32	4.60	2.05	19.37

The difference in mean TOT between conditions is statistically significantly different, in other words the mean TOT in the High condition is statistically significantly higher than in the Low condition.

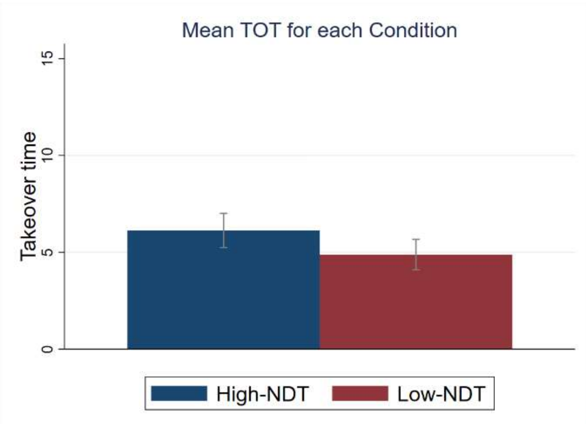


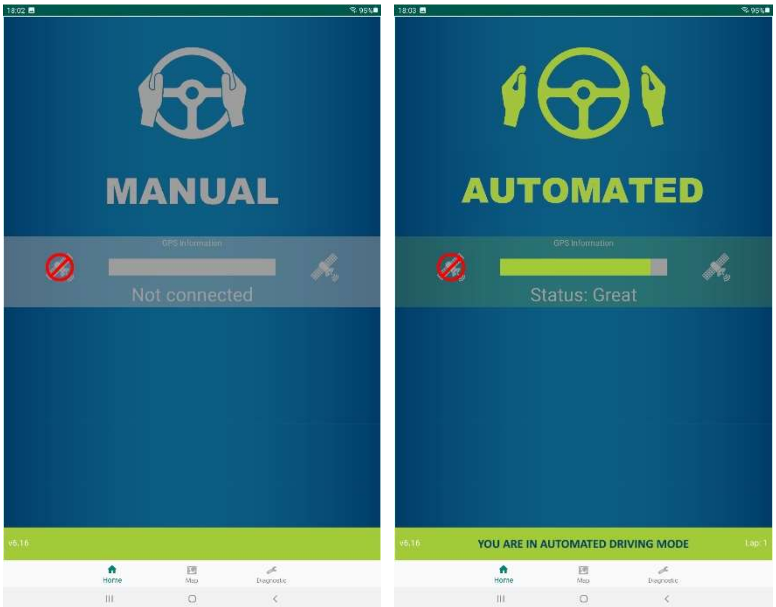
Figure 8: Mean TOT by condition (study 1)

Similarly, to previously observed TOT during WP1 study with ZOE2, most of the TOT are below 10s. The distribution for both conditions is shown in Figure 8, highlighting the increased occurrences of TOT measurements below 5 seconds in the Low condition. The total spread of TOT between conditions was similar with minimum TOT of 2.05 and 2.3 seconds respectively in High and Low, and maximum TOT of 19.17 and 19.37 seconds respectively.

4.1.2 RSIF Study 2, summary

Study 2 looked at how the driver of a conditionally automated vehicle (SAE J3016 Level 3) performed when asked to takeover (Takeover request, TOR) depending on different level of system transparency, all the while still performing a distracting NDT.

Participants were assigned to two transparency conditions, the High and Low conditions. The conditions differed solely by the visuals shown on the ZOE2's HMI. Compared to study 1 two graphical elements were added to the HMI: (1) GPS status information, and (2) pre-TOR warnings. Those additions were purely visual, there was no new auditory elements (as opposed to study 3).



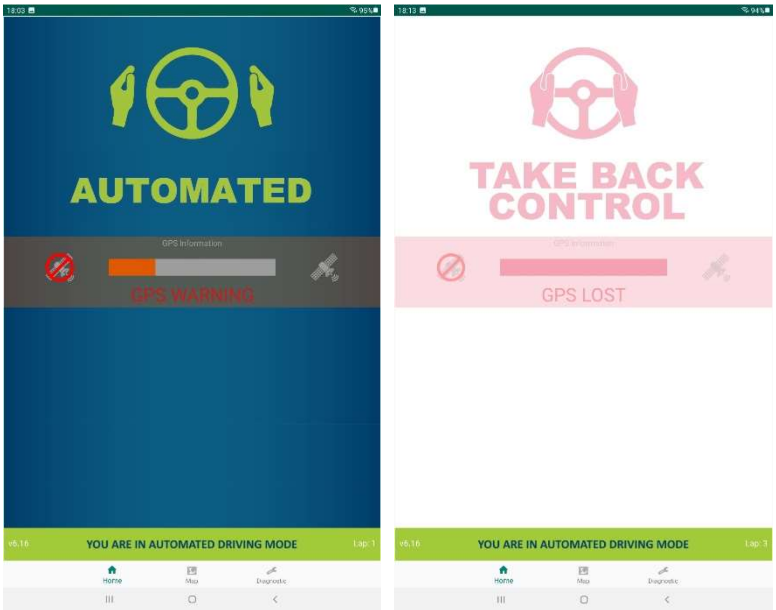


Figure 9: HMI view for study 2 High condition; manual (top left), automated (top right), warning (bottom left), TOR (bottom right)

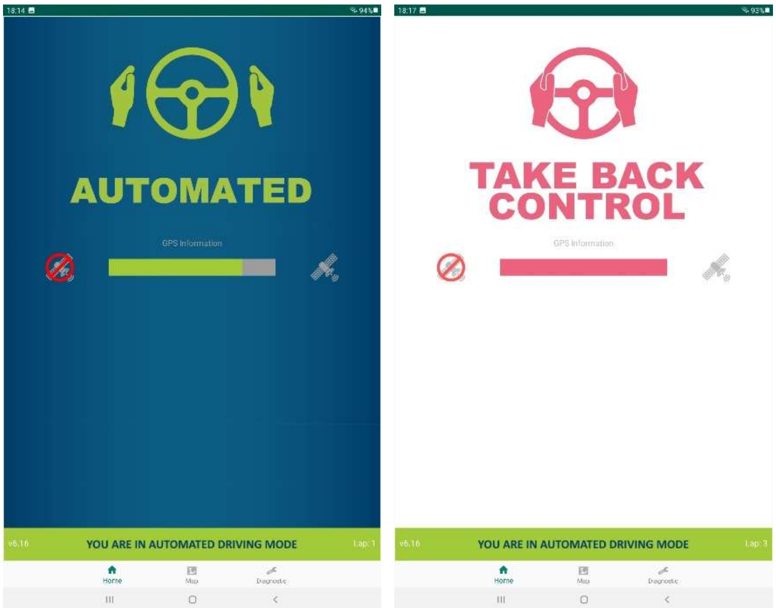


Figure 10: HMI view for study 2 Low condition; automated (left), TOR (right)

The GPS status information took the form of a status bar in the middle of the screen. This bar displayed the quality of the GPS signal and would display a warning if the quality was too low (which meant a TOR may be imminent). The status bar was both controlled by the live signal quality and by pre-programmed scenario events. In the High condition (Figure 9, top row) the status bar had a higher degree of information: the main quality bar, a background colour that would change alongside the quality bar, and a text that would explicitly display the status with words such as “Great”, “Good”, or “Poor”. The status bar would remain during a TOR event but with the words “GPS LOST” and flashing fully red (Figure 9 bottom right).

Pre-TOR Warnings would warn that a TOR was about to occur by showing there was an issue with the system. In study 2 the warnings were solely focused on GPS quality problem, so if the GPS quality was too low the status text would be replaced by the words "GPS WARNING" (see Figure 9 bottom left) and the status bar would flash.

In the Low condition (Figure 10) only the status bar was shown with no background and no explicit textual information, making it a lot less conspicuous. The behaviour was otherwise the same as in the High condition.

The NDT for study 2 was the same as the High condition from study 1: a 30 minutes-long video with a 21 questions questionnaire. The videos and questions were the same as in study 1 to enable inter-study comparison.

All participants experienced the same scenario with 30 minutes of driving on closed tracks, with a total of 7 laps. The scenario features three pairs of warning-TOR and three single warnings, organised as follow:

- Warning 1: Lap 1
- Warning 2: Lap 2
- Warning 3-TOR 1: Lap 3
- Warning 4-TOR 2: Lap 4
- Warning 5: Lap 5
- Warning 6-TOR 3: Lap 6

The location of those events is shown on Figure 11, the paired warnings and TOR are coloured the same, with the warnings represented by circles and the TOR by diamonds.

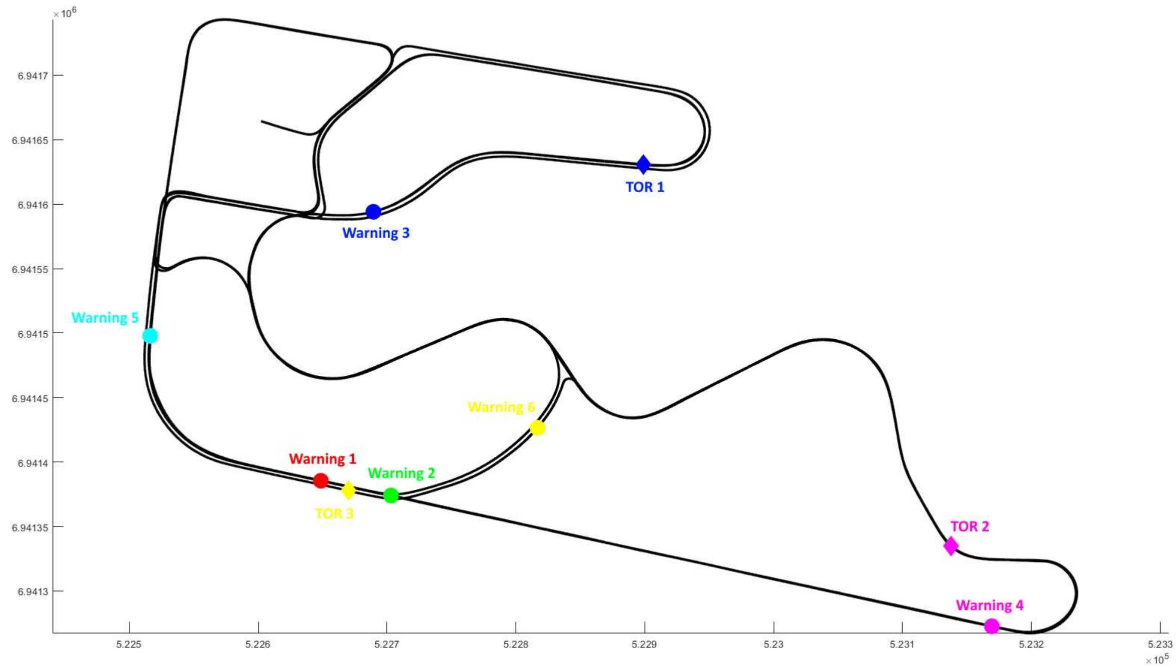


Figure 11: Take-over requests (TOR) and warning map for study 2

The mean measured TOT (Table 5) in the High transparency condition (M = 5.06 s; SD = 2.79 s) was not found to be statistically significantly different than the mean TOT in Low transparency condition (M = 4.97 s; SD = 2.64 s).

Please note that this finding does not include the cases where participants took back control of the vehicle before the TOR during the warning stage. This happened only 8 times over the 180 total planned Warning events (5x36), with only 4 participants.

Table 5: statistics for TOT by condition (study 2)

Condition	Mean	SD	Median	Min	Max
High Transparency	5.06	2.79	4.46	1.50	15.96
Low Transparency	4.97	2.64	4.10	1.62	12.20
Both	5.02	2.71	4.23	1.50	15.96

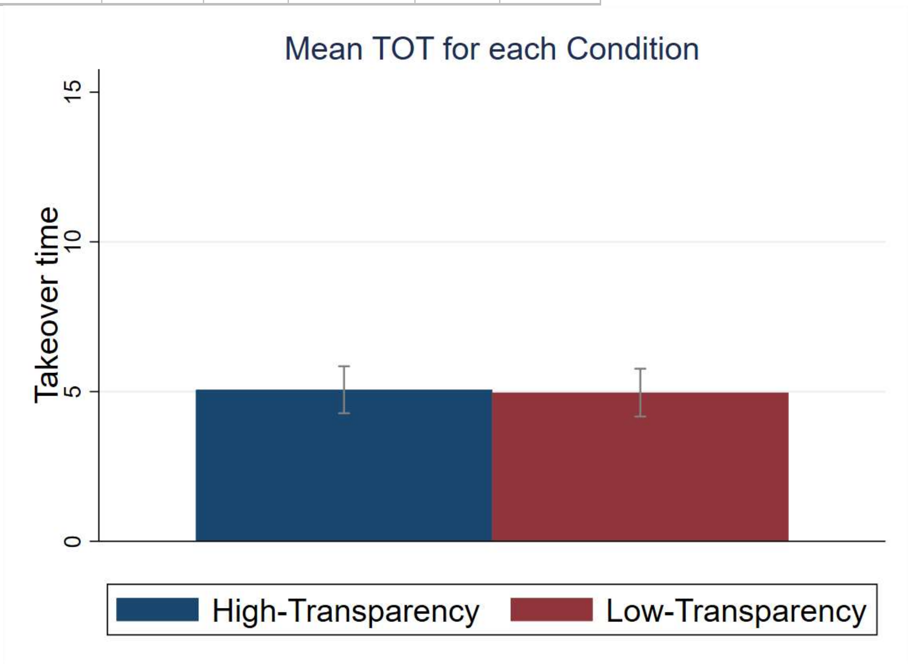


Figure 12: Mean TOT by condition (study 2)

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