Switching Back to Manual Driving: How Does it Compare to Simply Driving Away After Parking?

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ABSTRACT
Is there a difference in behavior when drivers start driving after parking compared to taking over from an autonomous driving car? In the former, the driving context switch (from static to driving) might be bigger than the latter, where drivers are already in a moving vehicle. This bigger difference might be paired with a decision to stop attending to any distracting task since drivers might find themselves in a different state after driving away. Participants drove a straight highway in a simulator. They either took over driving after being driven autonomously, or after being parked. Concurrently, we played distracting videos in the simulator. Participants looked more towards the road while the car was driving autonomously but there was no difference in driving performance and gazes towards the distraction after take-over compared to starting after parking. This implies that despite a difference in attention before take-over, the control switch is similar.

Author Keywords
Autonomous driving; driver distraction; parking; visual distraction;

ACM Classification Keywords
H.5.2 User Interfaces: evaluation/methodology, interaction styles; H.1.2 User/Machine Systems: human factors, human information processing.

INTRODUCTION
Over the last years cars are becoming more and more automated. The National Highway Traffic Safety Administration (NHTSA) defined standardized vehicle automation levels ranging from 0 (manual) to 4 (fully automatic). Similarly the Society of Automotive Engineers has standardized car automation levels ranging from 0 (no automation) to 5 (full automation) [23].

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The current technology includes driver aiding technologies such as lane departure warnings, lane keeping technology, emergency steering and adaptive cruise control [19]. In NHTSA nomenclature this is level 1 or level 2 automation, which assumes the human driver to monitor the environment and to be able to immediately take over control when necessary. Level 3 automation is expected to be rolled out in the coming years [5]. At this level the car takes over even more functionality including some monitoring of the environment. However, the human driver can still be asked to take over driving in situations where the car does not know how to operate best. An associated warning would be given ahead of time.

Introduction of new (in-) car technology sometimes leads to new risks. Research by Endsley and Kaber has shown that intelligent assisting technologies could improve safety but can also lower situational awareness [4]. Similarly a study by Gorter shows that half of the drivers that use adaptive cruise control (a system that controls longitudinal position) engages in secondary (distracting) activities [8]. Rudin-Brown and Jamson [21] demonstrate how several in-car technologies and changes of infrastructure that were intended to reduce driving-related risks, in fact *increased* the number of road accidents. The understanding is that this is due to overreliance on the technology. In autonomous driving research specifically, a recent meta-review suggests a similar trend: with increased automation, drivers tend to distract themselves more with other tasks (similar to how multitasking is very prominent in other parts of our lives [10]), which reduces their situational awareness and reaction time to sudden events [26].

Taken together, previous research suggests that distracted drivers are not always aware enough of their surroundings when taking over control from an autonomous vehicle. What is currently still unknown is whether this is specific to autonomous driving, or whether drivers could have been just as distracted when starting to drive from a stationary, non-automated position.

At first sight, these two options seem very different. In the autonomous driving condition drivers are already in the middle of a dynamic driving environment before they take over driving, whereas in the parked position they are not. Moreover, in the situation where a driver starts from a parked position the initiative for driving lies with them, whereas with the autonomous car the take-over is in response to a reached limit of the autonomous system (e.g. due to a traffic accident ahead).

Recent research suggests that there might be more overlap between the two situations, particular in cases where the driver has been distracted, which is likely for both parking and higher automation situations [8,12,26]. Strayer and colleagues [24] measured reaction time of drivers while driving through a city block. It took drivers that had interacted with an in-vehicle interface up to 27 seconds before their performance on driving and the detection-response task (DRT) [9] (a simple reaction task) was back at baseline level, even when the interaction happened while the car was stopped at a red light and when the interaction task already finished before driving started. This suggests that distracting effects can persist longer than initially thought. Moreover, it suggests that starting to drive after being parked might have similar risks as when taking over control from a previously autonomously driving vehicle. The current study is aimed at investigating this explicitly.

Our study focuses on how autonomous driving influences the driving performance of human drivers by comparing manual driving after a period of autonomous level 3 driving to driving after a period of being parked on the side of the road. Are previously parked drivers better at disengaging from a secondary task so as to fully engage with the driving task, compared to a situation where they take over from an automated car? If so, then we suspect that drivers of autonomous vehicles continue to glance at the distracting task more, once they take over driving - because they did not explicitly decide to disengage and because they are used to performing this task in a (autonomous) driving context.

To investigate this, we compared driver's gazes and driving performance after take-over, that is: do drivers look more at the road or at the continuing distracting task and does this reflect in their driving performance? We compared this between a situation where driving was taken-over after being parked compared to when taking over after being driven autonomously.

Figure 1. The DriveSafety driving simulator and the distraction video with landmarks on the display corners.

METHOD

Participants

Sixteen students (4 female) from the Electrical and Computer Engineering department of the University of New Hampshire took part for credit compensation on voluntary basis. The participants ranged in age from 18 to 29 years (M = 21.1, SD = 2.9 years). Driving experience ranged from 1 to 10 years (M = 4.5, SD = 2.6 years) with an average of 12,000 miles driven over the last 12 months (SD = 24,400 miles). The experiment was approved by the UNH Institutional Review Board for the Protection of Human Subjects in Research. Informed consent was obtained from all participants.

Apparatus and materials

Figure 1 shows our DriveSafety desktop driving simulator with three 24" displays, a full size steering wheel and pedals, which was used for the driving task. Participants viewed the displays from a distance of about 85 cm, giving a horizontal field of view of 90°.

The driving environment was a daylight straight 4-lane (2 lanes each direction) rural freeway throughout the whole experiment. Participants were asked to follow a yellow car. Apart from this lead vehicle there was no other traffic. The lead vehicle drove at a speed of 50 mph (80 km/h).

To ensure that participants had to steer throughout the experiment a constant lateral wind was added in the simulation. This wind alternated direction (from left or right) every 7 seconds and had a strength of 70 N·m.

Participants wore Pupil Labs eye trackers to record the gaze and participants' field of view. For ease of analysis purposes, the simulator displayed 2D barcodes at the four corners of both outer displays and on the laptop, which we used as surface landmarks for the eye tracker (Figure 1).

Tasks

During trials, two situations could occur: starting from being parked or taking over from autonomous driving. In the parked condition, participants were parked on the side of the road for 2 minutes followed by a visual warning (blinking icon of a steering wheel with a short displayed message to start driving) and auditory warning (beep every second) to indicate that driving had to start, see Figure 2. Participants had up to 7 seconds to take over, and the alerts continued until the driver started driving. After 7 seconds, the lead vehicle started driving. The drivers had to follow this car.

In the autonomous condition, the car drove autonomously for 2 minutes: it controlled both lateral and longitudinal position and followed the lead vehicle at a speed of 50 mph at a distance of 160 feet (50 meter) which resulted in a headway time of 2.25s. The take-over-request was identical to the parking condition with visual and auditory warnings for up to 7 seconds. Control could be taken by pressing the brake or accelerator pedal and by subsequently manually following the lead vehicle at a comfortable distance. Taking over by pressing one of the pedals within 7 seconds is similar to a previous study about take-over behavior by Gold et al. [7].

Figure 2. Example of the visual take-over request to notify participants that they have to take over from the autonomous driving car. The visual request was accompanied with an auditory warning.

In each condition the trial ended two minutes after the take-over. This results in a total trial duration between 4 minutes and 4 minutes and 7 seconds depending on how quickly participants took over.

As we expect that drivers may normally not pay full attention to the road in an autonomous car [26], we added a distracting side-task. This task was shown on a Dell XPS 13 laptop, located at the right side of the steering wheel as can be seen in Figure 1. The laptop showed a continuous video with the volume playing at a clearly audible level.

We consider watching a video to be a natural secondary task for drivers in an autonomous car. Watching a video before taking over from a highly automated vehicle has been shown to evoke a decrease in driving performance after the take-over [28]. We showed a children's cartoon with no spoken dialogue and decided on playing the same video for every participant to maintain consistency. Participants were not specifically instructed to watch the distraction but were asked to behave as they would normally do in a driving environment.

Design

We used a two-factor within-subjects (repeated measures) design to investigate differences in the driving performance and distraction level between driving (1) after autonomous driving against (2) after parking. Conditions were blocked and block-order was fully counterbalanced. We also compared performance before take-over with after take-over.

Procedure

Participants were given a brief explanation of the procedure and measurements that would be taken. After that they were asked to fill out the consent form and questionnaire to collect demographic data before wearing the eye tracker and taking a seat behind the steering wheel. The seat position and height could be adjusted for a comfortable driving position.

Participants then performed two experimental blocks. Each block started with a practice trial to prevent novelty effects and to make sure participants understood the procedure and felt confident driving the simulator. Once participants at least performed one complete practice trial, the experimental trials started. For each condition, we measured performance on two trials.

During the recording the experimenter left the participants unaccompanied, in order to avoid biasing them to focus more on the road than drivers would do without being watched.

Measures

We measured five aspects of behavior, of which two relate to driving performance and three to eye-gaze. Unless otherwise noted, we used a paired t-test to compare performance across conditions with an alpha level of .05 for significance.

Take-over time

We recorded the time between the take-over request and the control switch, as indicated by pressing either the accelerator or brake pedal. This time interval might be an indicator of a driver's distraction level before and during the take-over request and can show a sign of unwillingness of participants to take over control. The measurement had a ceiling value of 7 seconds.

Standard deviation of lane position

The calculated statistic was the standard deviation of lane position (SDLP), per SAE J2944 [22]. We recorded the car's distance to the center of the road at a rate of 10 Hz. High variance in lateral position indicates poor driving performance, which could be caused by cognitive or visual distraction.

Gazes toward distraction

For both conditions we counted the number of frames where gaze was identified on the distraction screen after take-over. Every 30 frames is 1 second.

We also calculated fixations, which are defined as gazes of 0.15 seconds or longer using a dispersion threshold of 1 degree of visual angle as recommended by the work of Blignaut [3].

Percent road center

The percent road center (PRC) shows how much time participants look at the center of the road. The measure is calculated per individual trial. The PRC is the percentage of gaze points that fell within a circle. The mean of all gaze points of each trial is the center point of the circle and the diameter of the circle is calculated as 6 degrees of the participants' visual field. Note that the center of the circle is not necessarily the middle of the display nor the center of the road since the eye tracker calibration could be slightly off. We only used the gazes towards the center display for the calculations since gazes towards the distraction will interfere with determining the road center.

While PRC is sometimes calculated using the fixations that fall within the defined circle, work of Ahlstrom et al. [1] shows that the step of conversion from gaze towards fixations can be skipped for determining the PRC since simpler gaze data showed similar results.

The PRC is used as a measure in a similar study by Merat et al. [20] and has been identified as a good parameter to assess driver distraction [11]. As visual distraction increases the calculated PRC values decrease whilst PRC values increase for audio-only tasks and for tasks with higher driving task complexity [25].

Percent dwell time

As a proxy for attention to driving, we calculated percent dwell time (PDT) on the road. For the calculation of the PDT we counted the number of frames where the gaze of participants was identified as being on one of the predefined surfaces of the driving simulator (i.e., looking at one of the three screens) and the number of frames with gazes identified off these surfaces. We then calculated the percentage of time looking at the simulator.

We calculated the PDT for data before and after the take-over. The data before take-over is based on the last 100 seconds before drivers received the request to take over the controls and the data after take-over is based on gaze data from the point where the drivers touch the accelerator or brake pedal.

The PDT has been proven a good indicator for visual distraction [16].

RESULTS

Take-over time

There was no difference in take-over time between the autonomous driving (M = 2556, SD = 1158 ms) and parking (M = 2214, SD = 1636 ms) conditions, $t(15) = 1.489$, p = .157. All participants reacted within the 7 second threshold.

Standard deviation of lane position

There was no significant difference in standard deviation of lane position between driving after being parked (M = 0.37, SD = 0.11 m) compared to after autonomous driving (M = 0.38, SD = 0.096 m) with $t(15) = .275$, p = .787.

Gazes toward distraction

Participants hardly looked at the distraction after the take-over. This causes the number of gazes to be relatively low for both parking (M = 30, SD = 62 frames) and autonomous trials (M = 27, SD = 75 frames) during the two minutes after take-over. There might be an effect of time after take-over on number of gazes and an interaction with driving type. We used a 2 (time after take-over: two segments of 1 minute) x 2 (situation: parking or autonomous) within-subjects ANOVA. The time after take-over had an insignificant influence on the number of gazes with $F(1, 15) = 2.123$, p = .166, there was no significant effect for driving type with $F(1, 1) = 0.054$, p = .82 and no interaction effect between time after take-over and the type of driving with $F(1, 15)$ = 0.158, p = .697.

We found no difference of fixation duration between parking trials (M = 341, SD = 180 ms) and autonomous trials (M = 423, SD = 378 ms) with $t(15) = -0.19$, p = .851.

Percent road center

Figure 3 shows the locations of the gazes towards the center display during one single trial of one participant. A circle is drawn to illustrate the 6 degrees of visual field of the participant. The center of this circle is the mean of all the gazes of this single trial. It is visible that the mean location is not in the center of the display, as the circle is not exactly centered in the figure.

When we look at the overall percent road center (PRC) across all participants, this does not show a difference between the parking condition (M = 80.6%, SD = 12.7%) and the autonomous condition (M = 78.4%, SD = 20.8%), $t(15)$ = .625, p = .542. However, might this differ during the course of a trial?

To get a better understanding of how PRC develops over time during a trial, we also plotted the PRC of both conditions as a function of time using bins of 5 seconds, see the top of Figure 4. In the bottom of the figure, we plotted the speed of both conditions over time. This was done as the starting speed of both conditions is different (i.e., at speed in autonomous, and at 0 for parking) which in turn might affect the PRC.

Participants could for example focus their gaze towards the lead vehicle while speeding up and thereby overshoot the speed limit. Figure 4 shows the point in time where the mean speeds of both conditions reach the same level, indicated by the vertical dashed line. The grey bars around this line is the standard deviation in time when participants reached the same speed (M = 15.6, SD = 3.5 s).

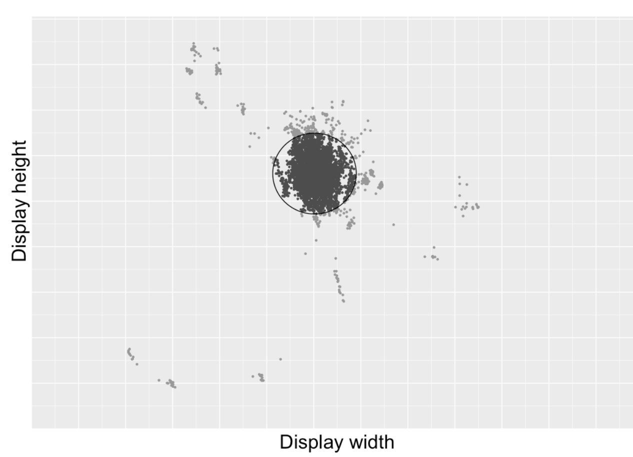

Figure 3. Plot of the locations of all the gaze positions towards the center display during one single trial (N=6967). The 6° visual circle around the calculated center is also shown.

Figure 4. Top-figure: The percentage of looking at the road center (PRC) as a function of time. Bottom-figure: the average driving speed over time. In both figures, the vertical dashed line shows the moment in time where both conditions have the same speed, with the standard deviation displayed as vertical grey bars. The error bars and ribbon show the standard error values of each metric.

We used a 24 (time after take-over: buckets of 5s) x 2 (situation: parking or autonomous) within-subjects ANOVA to determine the effect of time and condition on the PRC. The time after take-over had a significant influence on the PRC with $F(1, 23) = 3.73$, $p < .001$, there was no significant effect for driving type with $F(1, 1) = 0.93$, $p = .542$ and no significant interaction effect between time after take-over and the type of driving with $F(1, 23) = 0.55$, $p = .954$. As Figure 4 shows, the PRC gradually increases in the first 15 to 25 seconds and then stabilizes

Percent dwell time

Figure 5 plots the PDT score for the autonomous driving condition (dark grey bars) and the parking condition (light grey bars) for the 100 seconds before taking over control (left two bars) and 2 minutes after taking over control (right two bars). A 2 (timing: before, after take-over) x 2 (situation: parking or autonomous) within-subjects ANOVA revealed that there was a main effect of timing, such that drivers looked more at the road after taking over, $F(1, 15) = 78.75$, $p < .001$. There was also a main effect of driving situation, $F(1, 15) = 7.39$, $p = .016$. This was influenced by an interaction effect, $F(1, 15) = 7.48$, $p = .015$.

As Figure 5 shows, the interaction was such that before the take-over, the participants looked almost twice as often at the road in the autonomous driving condition (M = 48%, SD = 9.4%) compared to the parking condition (M = 27%, SD = 6.22%), whereas after take-over both groups spent roughly a similar amount of time gazing at the road (in both conditions M = 99%, SD = 0.5%).

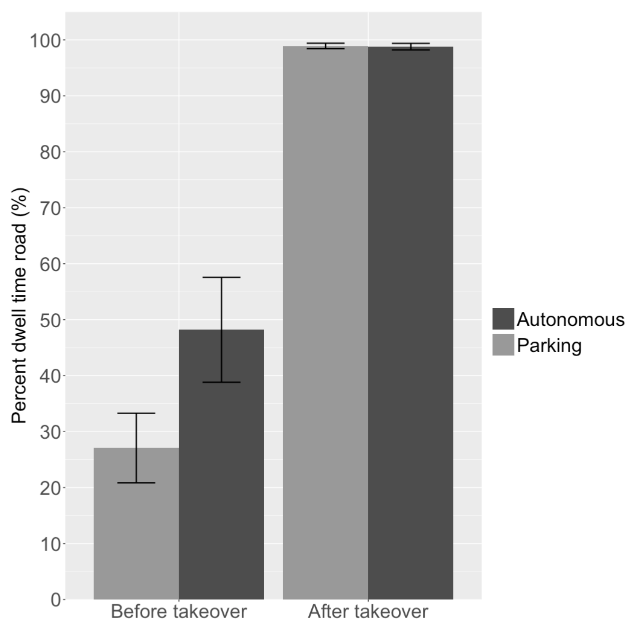

Figure 5. Percentage of time spent looking at the road before and after the take-over for both autonomous driving and parking conditions.

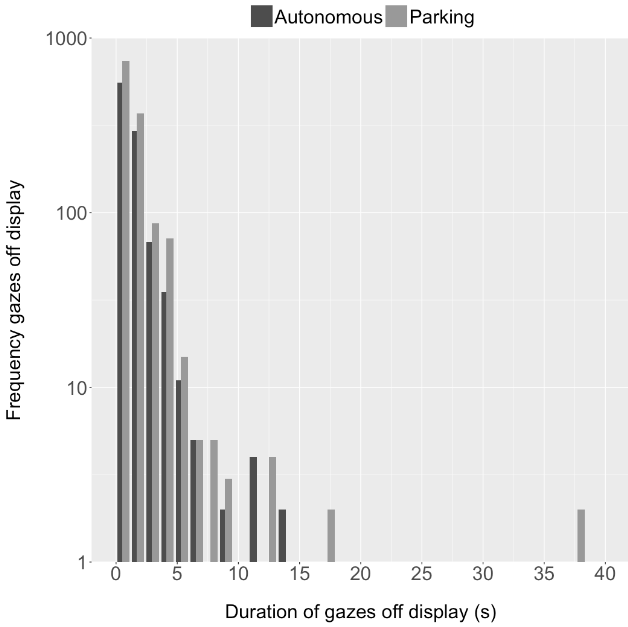

Figure 6. Histogram of the duration of gazes off the road before the take-over. The y-axis is in log scale.

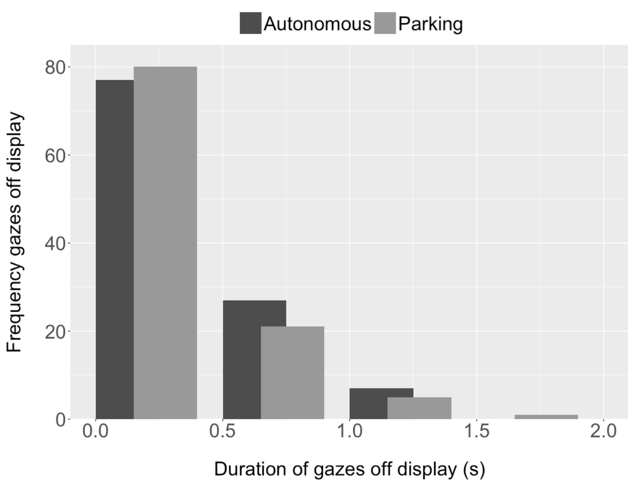

Figure 7. Histogram of the duration of gazes off the road after the take-over.

To get an idea of the duration of gazes away from the road per occurrence of looking away, we counted the number of consecutive frames of which the gaze was identified as off-simulator-surface and calculated the time of those events by dividing the number of frames by the framerate. We plotted histograms of the durations and frequency of instances of looking away from the simulator displays across all the trials *before* the take-over in Figure 6 and *after* the take-over in Figure 7. The histogram is plotted with durations binned in bins of 0.5 second. The frequency of glances is significantly higher before take-over (M = 73.8, SD = 32.5) compared to after take-over (M = 9.9, SD = 11.5), as can be seen by the higher frequencies in Figure 6 compared to Figure 7 (note that Figure 6 uses a log scale). To test whether this difference was statistically significant, we used an unpaired t-test since not every participant looked away from the road after the take-over. The difference was significant with $t(10.1) = 39.76$, $p < .001$.

In addition, the duration of glances is higher before take-over (M = 2.54, SD = 1.34 s) compared to after take-over (M = 1.34, SD = 0.14 s), which is reflected by the broader distribution of data in Figure 6 (before) compared to Figure 7 (after). Note again that the range of the horizontal axis is different between the two figures. We found a significant difference with an unpaired t-test, $t(9.1) = 29.8$, $p < .001$.

There were two instances where participants looked away for around 38 seconds. Both instances took place while these participants were parked before driving.

The NHTSA analyzed the risk of gazes away from the road and concluded that gazes away with a duration longer than 2 seconds significantly increase crashing risks [13]. In our experiment the longest gaze away from the road after the take-over was 1.9 seconds. This means that none of the participants increased the risk significantly by looking away too long. Nevertheless, while the car was driving autonomously, participants looked away from the road for longer than 2 seconds 174 times in total.

DISCUSSION

The results of the current study show no differences in driving when taking over control of the car after being parked compared to taking over after being driven by an autonomous driving car. For both conditions, participants returned their gaze to the driving task when requested to take-over, despite that they also had the opportunity to continue to look at a distracting task (a video clip). This suggests that there was a low engagement with the distraction in the first place or that participants could easily disengage from the distraction to direct their attention towards the driving task.

The similarity in take-over time seems to show that participants are quickly ready and able to switch tasks during both presented conditions. As Zeeb [27] argues, the take-over time is primarily depending on cognitive processes and not motor processes. This indicates that the cognitive load for taking control after autonomously driving and starting with driving after parking seems to be similar with the current environment.

There was a difference in eye-gaze behavior before the take-over though. Before take-over, participants looked away from the road more when parked compared to when driving in an autonomous car. However, in both conditions there were at least some glances at the road. Whether this is 'enough' for autonomous driving will depend on context. Around 50% of the time drivers did not look at the road, and this might have led them to overlook critical information. As the results about autonomous driving show, participants turned their gaze away from the road for longer than 2 seconds fairly often. In accordance with NHSTA guidelines [13], this would significantly increase the crash-risk in nonautonomous driving. However, whether this is similar for autonomous driving is an empirical question.

The percentage of gazes towards the road center over time is in agreement to the results of Merat et al. [20]. There is a lower percentage right at the switch to manual control and consequently a stabilization (see Figure 4). The general percentage turned out slightly higher in the current study. This might be due to the absence of traffic and road signs. The focus towards the center shows no difference between taking over after parking and taking over after driving autonomously. This suggests that the amount of distraction is similar in both conditions [11,25].

The duration or amount of gazes towards the distraction after take-over showed no significant difference between the two conditions. Similarly the percent dwell time towards the road was high compared to previous research [6,15,18]. This may indicate that participants were not interested in watching the video or could easily disengage from the distraction to focus their attention toward the driving task. Future research could compare parking to autonomous driving with other kinds of distraction.

LIMITATIONS

A limitation in our work is that participants controlled a desktop driving simulator from a desk chair, which might not feel as driving. A better test of our hypothesis would be a high fidelity driving simulator. Previous research has shown significant differences in driving simulator fidelity [2].

The two minutes of looking at the distraction during autonomous driving or parking is relatively short compared to other studies about highly automated vehicles [7,20,27,28]. This might have resulted in participants anticipating on the take-over and a lower distraction. The benefit of the shorter trials is that we could run repeated trials with every participant to improve the validity of the results.

In our parking condition, it was not completely up to the driver when they started driving. After 2 minutes, an alert was given that they should start. Although it was up to the driver when they started to initiate the drive, after 7 seconds a lead car would start driving, which they had to follow. This differs from normal traffic conditions, where starting to drive after being parked is typically initiated by the driver. Our situation is more comparable to being parked at a traffic light, where a driver knows they have some time before they need to drive again, but it is not fully up to them.

The presented environment was intentionally an ideal situation with a straight road and no other traffic in combination with a single source of distraction. Further research with different environments and distraction types is needed before generalizations can be made.

Finally, the group of participants were young students from an engineering department. Having a broader selection of drivers would provide higher ecological validity.

CONCLUSION

Rapid advances in technology will likely allow automated vehicles to be deployed in large numbers relatively soon. For this reason is important that research is conducted on how user interfaces in automated vehicles can support safety [14,17]. Understanding driver distraction and the lasting effect of it [24] may be vital to improving road safety for automated vehicles. Research shows that taking over from a previously autonomous driving vehicle can result in decreased driving performance and decreased situational awareness [7,20,26,28].

We approached the distraction during the take-over from a novel perspective by comparing it to driving away after being parked. Our results show no differences in driving performance nor in engagement in distraction after the take-over. This suggests that within the tested context starting to drive after parking is similar to taking over from an autonomous car.

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