Switching back to manual driving: How does it compare to driving away after being parked?

Master thesis

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ABSTRACT

Is there a difference in behavior when drivers start driving from a stationary position such as being parked compared to when they take over control from an autonomous driving car? In the stationary situation, drivers are initially standing still and moving after. This might be a bigger change in the driving context compared to the difference between autonomous driving and manual driving, where both scenarios entail a moving vehicle with just manual control as change of context. If drivers are distracted while being in an autonomous moving vehicle and got used to the fact that they can, the smaller difference between autonomous driving and manual driving might lower the urge to stop attending the distraction. That is, drivers might have gotten habituated to distraction in a moving vehicle and could remain distracted, even when they take over and drive manually. In our study we try to explore this behavioral adaptation effect by comparing a situation where adaptation could play a role (taking over from autonomous vehicle) to a situation where it could not (driving away after being stationary). Participants drove a straight highway in a simulator and were asked to take over driving after autonomous driving or after being stationary for 2 minutes. During the whole experiment distracting videos played on a laptop next to the steering wheel. Participants looked more towards the road while the car was driving autonomously compared to when the car was stationary. Surprisingly, drivers showed no difference in driving performance and gazes toward distraction after taking over compared to starting after being stationary. This result suggests that despite a difference in the amount of attention dedicated to the road before taking over, switching to manual driving is similar to simply starting to drive within the presented context. Our results indicate that, upon take-over, drivers seem to equally disengage from the distraction for both taking over and starting to drive. There is no sign of lasting adaptation considering distraction when taking over from an already moving vehicle.

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INTRODUCTION

New technologies are continuously considered and introduced in vehicles and infrastructure. These changes in the driving context could have implications on driver behavior with increased risk as result. To lower accident rates and increase general road safety it is important to understand the capabilities, limits and implications for drivers of the introduced novelties. One of the ways to gain this better understanding is to study driver behavior and performance in different settings and compare and describe the results. The current study focusses on extending our knowledge on the human factors of vehicle automation. More specifically, we try to explore a possible explanation of decreased driver performance when taking over control after some time of autonomous driving.

Autonomous driving is a well-studied topic with already over 26.000 Google Scholar results since the start of 2016. Among those studies we find research focused on driver behavior and others on developing and testing autonomous driving cars. Within the industry multiple frameworks have been defined. For example, the National Highway Traffic Safety Administration (NHTSA) in the United States defined standardized vehicle automation levels ranging from 0 (manual) to 4 (fully automatic) [24] (Figure 1).

Over the last years cars are becoming more and more automated [5]. The current technology includes driver aiding technologies such as lane departure warnings, lane keeping technology, emergency steering and adaptive cruise control [18]. 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 high level 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.

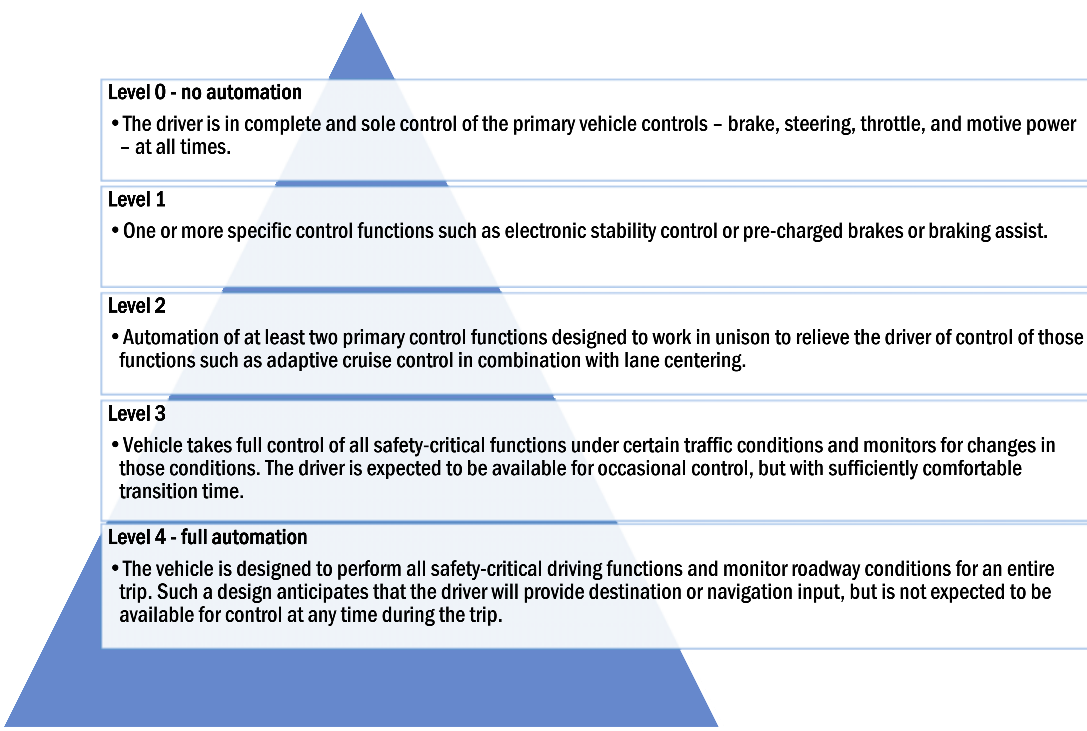

Figure 1. NHTSA automation levels from 0 (no automation) to 4 (full automation)

Research by Endsley and Kaber has shown that higher intelligent assisting technologies could help improve road safety but can also lower situational awareness of drivers because of higher distraction levels [4]. Similarly, a questionnaire by Gorter shows that half of the drivers that use adaptive cruise control (a system that controls longitudinal position) engage more in secondary (distracting) activities [8]. Rudin-Brown and Jamson [27] 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, that is to say that drivers assume that the novel safety measures allow them to take more risks. In autonomous driving research specifically, a recent meta-review suggests a similar trend: with increased automation, drivers tend to distract themselves more with secondary tasks (similar to how multitasking is very prominent in other parts of our lives [10]), which reduces their situational awareness and increases their reaction time to sudden events [33].

Taken together, previous research suggests that increased automation leads to distracted drivers which are not always aware enough of their surroundings to safely take over control when necessary. What is currently still unknown is whether this decrease in driving performance after take-over is specific to autonomous driving, or whether drivers could have been just as distracted when starting to drive from a stationary, non-automated position. A recent study showed significantly higher distraction rates for drivers that were stopped at a red light compared to when they were driving [12]. Drivers were more often seen interacting with cellphones, talking or eating. Something that is similar to distraction in automated vehicles [8]. This similarity means that it might be useful to study driver behavior during and after being stationary to learn more about autonomous driving.

Comparing driving away after being stationary to taking over from an autonomous vehicle initially seems very different. During driving autonomously (automation level 3), drivers are already in the middle of a dynamic driving environment before they take over driving, whereas in the stationary position they are not. Moreover, in the situation where a driver starts from a stationary position the initiative for driving generally lies with them, whereas with the autonomous car the take-over can be unexpected, in response to a reached limit of the autonomous system (e.g. due to a traffic accident ahead).

Recent research by Strayer and colleagues [30] suggests that there might be more overlap between the two situations than initially expected, in particular with cases where the driver has been distracted. In the study by Strayer and colleagues participants drove at various speeds on a real road with various traffic situations, including stops at traffic lights. Meanwhile the researchers recorded reaction time of participants using the detection-response task (DRT) [9], a simple reaction task that has been linked to driver distraction and workload. It took drivers that were distracted by interaction with an in-vehicle interface up to 27 seconds before their reaction time and was back at baseline level (a non-distracted situation). This was even the case when the interaction happened while the car was stopped at a red traffic light and when the interaction task already finished before participants started to drive again. This suggests that the influence of distraction can persist longer than initially thought. Specifically, it suggests that starting to drive after being stationary at a red light might have similar risks compared to taking over control from a previously autonomously driving vehicle if during both scenarios drivers were distracted before. The current study is aimed at investigating the difference between the two conditions difference 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 stationary. The previous paragraph described a possible similarity between the two conditions but we might also find a behavioral difference caused by adaptation. Drivers in an autonomous vehicle might get habituated to distraction while being in a moving vehicle. In other words, an adaptation effect that last for a certain duration similar to driving speed adaptation [28]. Speed adaptation is the process of drivers getting used to driving speeds for some time and consequently incorrectly estimating lower and higher speeds. Rudin-Brown describes adaptation as intentionally or unintentionally learning to handle situations [27]. In the autonomous moving vehicle context, drivers might learn that they can allow themselves to be distracted in a moving vehicle. The learned behavior can consequently unintentionally still influence their behavior after take-over since a part of the environment is unchanged (the moving vehicle). The only difference after take-over is that drivers control the vehicle themselves. The theory of Rudin-Brown and knowledge about speed adaptation lead us to hypothesize that moving-vehicle adaptation exists and might result in lasting increased distraction rates after the take-over.

In contrast to taking over after driving autonomously, starting to drive after being stationary is a relatively bigger difference between the before and after take-over states without the possibility of getting used to distraction in a moving vehicle. The clearer switch between two situations can result in a stronger disengagement from distraction and more focus towards the driving task after take-over.

We try to answer the following question: are previously stationary 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 a difference is found, we suspect that, after taking over, drivers of autonomous vehicles continue to glance at the distracting task more often and longer which could reflect in a lower driving performance. This could suggest that the moving-vehicle adaptation in relation with distraction is present in an autonomous driving context.

To answer if there is a difference in distraction disengagement after being stationary and driving autonomously, we compared driver's gazes and driving performance before and after take-over. More specifically, what is the amount of gazes and time looking at the road and distraction before and after take-over and how is the driving performance? We compared the results of these observations between a situation where drivers started to drive after being stationary compared to when taking over from an autonomous driving vehicle.

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 2 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 passenger car. Apart from this lead vehicle there was no other traffic. The lead vehicle drove at a speed of 50 mph (80 km/h).

Figure 2. Overview of the DriveSafety driving simulator and the distraction video with the markers which the eye tracker can use as landmarks.

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 head-mounted Pupil Labs eye trackers to record the pupil and participants’ field of view at 30Hz (Figure 3). 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 2). This allowed us to recognize the simulator and distraction surfaces and quantify the gaze locations on every surface over time.

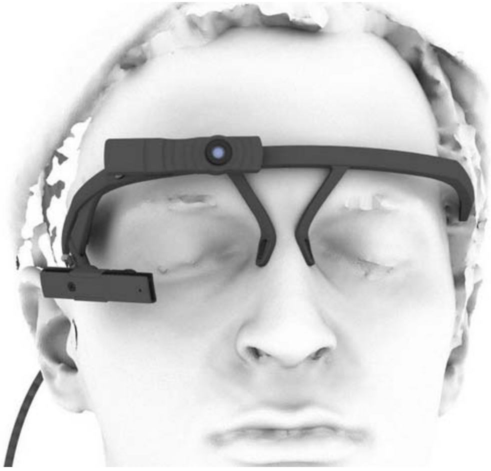

Figure 3. Render of the pupil labs eye tracker. Source https://pupil-labs.com/

Tasks

In the driving environment, two situations could occur: starting from being stationary or starting from autonomous driving. In the stationary condition, participants were parked on the road for 2 minutes. This was followed by a visual warning (blinking icon of a steering wheel with a short displayed message to take the wheel and start driving) and auditory warning (beep that beeps every second) to indicate that driving had to start, see Figure 4. Participants had up to 7 seconds to take over, and the alerts continued until the driver started driving. After 7 seconds or when the participant started to drive, the lead vehicle started to drive. The drivers had to follow this vehicle throughout the rest of the trial.

Figure 4. 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 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 stationary 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 touching one of the pedals within 7 seconds is similar to a previous study about take-over behavior by Gold et al. [7].

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 while driving an autonomous car [33], we added a 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 2. We performed 4 pilot experiments in which participants played a game of hearts as a distraction task before taking over. The game was intended to induce cognitive and visual distraction and a certain willingness to continue playing after taking over. Both eye tracking data and participant feedback showed that participants felt no urge to continue interacting with the game while driving. The game also consists of several game states, each of which can be active during the take-over request. This also resulted in inconsistency among trials and experiments.

As Radlmayr [25] has shown, visual distraction results in similar take-over behavior compared to cognitive distraction which led us to choosing the distraction based on other properties such as whether the task is a naturalistic distraction. We consider watching a video to be a potential source of distraction for drivers in an autonomous car. With dashboard displays, tablets and smartphones always around and connected to the internet, watching a video is more accessible than ever before. Llaneras et al. [20] showed that increased automation increased drivers' engagement in watching videos. Additionally, in a recent fatal crash involving the Tesla Autopilot (NHTSA level 2 automation) the driver allegedly watched a video on a mobile DVD player while he was supposed to monitor the driving aid [19,31].

The video is intended to induce visual distraction before, during and after the take-over and has been used as so in previous research [23]. Additionally, 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 [35].

In our study participants watched a children's cartoon with no spoken dialogue to account for varying levels of English proficiency. To maintain consistency across the experiments we played the same video for all participants. The video played continuously throughout the whole experiment as can be seen on Figure 2. The volume played at a clearly audible level and 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 being stationary. Conditions were blocked and block-order was fully counterbalanced. We also compared performance before take-over with performance 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. Subsequently participants were asked to put on the eye tracker and take place 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 (Figure 5).

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.

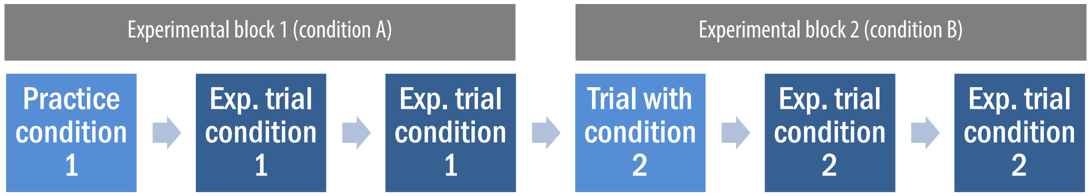

Figure 5. Flow of experiment procedure illustrating the two experimental blocks that each contain a practice trial and two experimental trials. The two experimental blocks are paired with the two conditions of which the order was counterbalanced across all participants.

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 start of the take-over request and the actual control switch, which is the moment when the participants presses either the accelerator or brake pedal. A difference in take-over time might be an indicator of a driver's distraction level before and during the take-over request. Additionally, the measure can be a sign of engagement and unwillingness to take over control. The measurement had a ceiling value of 7 seconds to force participants to take over at some point.

Standard deviation of lane position

The calculated statistic was the standard deviation of lane position (SDLP), per SAE J2944 [29]. We recorded the car's distance to the center of the lane at a rate of 10 Hz. High variance in lateral position indicates poor driving performance, which could be caused by cognitive or visual distraction [26].

Gazes toward distraction

For both conditions we counted the number of frames of which the gaze was identified as being towards the distraction before and 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 the percentage of total time that participants look at the center of the road. The measure is calculated per individual trial using all the gaze points that fell within or outside a defined 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 and individual differences in gaze behavior could also change the mean center. 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. [22] 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 [32]. Since all interaction during the given driving task happens in the road center and mirrors and instrument panel are not displayed we can consider gazes outside of the circle less attentive to the driving task.

Percent dwell time

As a proxy for attention to driving, we calculated percent dwell time (PDT) on the road by exporting the gaze data from the Pupil Player software as seen in Figure 6. 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 driver 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.

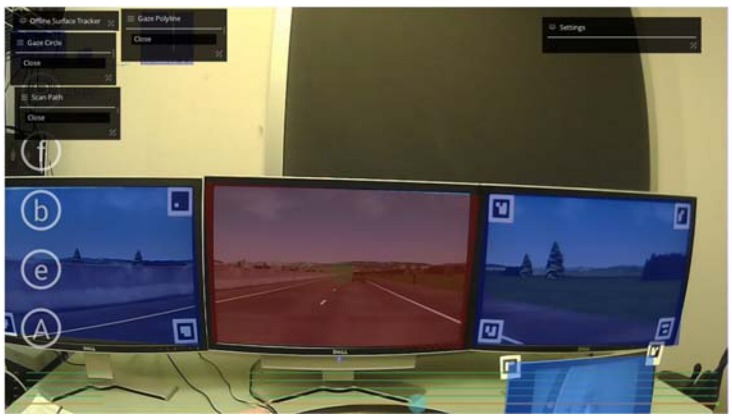

Figure 6. Pupil player software used for post processing the gaze data. The four recognized surfaces are filled with half transparent colors ranging from blue to red depending on how much time the participants' gaze is detected on the surface.

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.

Despite some overlap with the PRC measure we believe that both measures have different properties. Looking at the peripheral parts of the road can be considered as a stronger driving engagement compared to completely looking away from the road. The PDT has been proven a reliable indicator for visual distraction [16,21].

RESULTS

Take-over time

There was no difference in take-over time between the autonomous driving condition (M= 2556, SD = 1158 ms) compared to the stationary condition (M = 2214, SD = 1636 ms), $t(15) = 1.489$, $p = .157$. All participants reacted within the set threshold of 7 seconds.

Standard deviation of lane position

There was no significant difference in standard deviation of lane position between driving after being stationary (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 being stationary (*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: stationary or autonomous) within-subjects ANOVA. The time after take-over had no significant effect on the number of gazes, $F(1, 15) = 2.123$, $p = .166$, there was also no significant effect for driving type, $F(1, 1) = 0.054$, $p = .82$ and no interaction effect between time after take-over and the type of driving, $F(1, 15) = 0.158$, $p = .697$.

We found no difference of fixation duration between stationary 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 7 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.

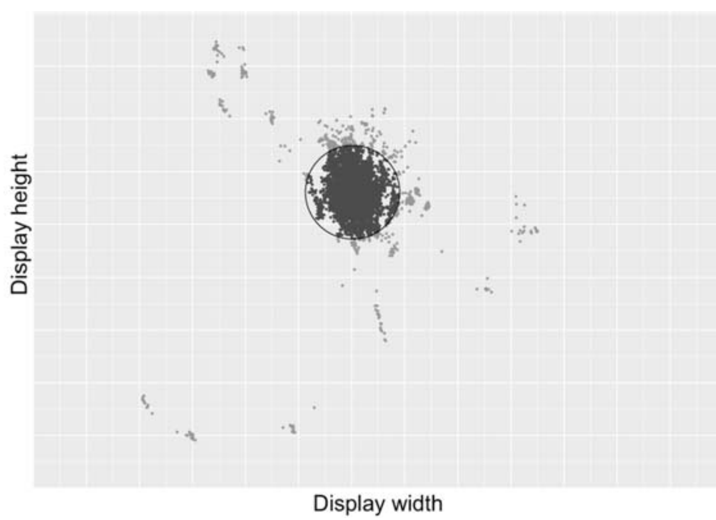

Figure 7. Plot of the locations of all the gaze positions towards the center display during one single trial (N=6967). The 6° visual circle around the calculated center is also shown.

When we look at the overall percent road center (PRC) across all participants, this does not show a difference between the stationary 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, this is visualized in the top of Figure 8. 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 stationary) 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 8 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).

We used a 24 (time after take-over: buckets of 5s) x 2 (situation: stationary 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 $F(1, 23) = 3.73$, $p < .001$. As Figure 8 shows, the PRC gradually increases in the first 15 to 25 seconds and then stabilizes. 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 $F(1, 23) = 0.55$, $p = .954$.

Figure 8. 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.

Percent dwell time

Figure 9 plots the PDT score for the autonomous driving condition (dark grey bars) and the stationary 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: stationary 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, $F(1, 15) = 7.48$, $p = .015$.

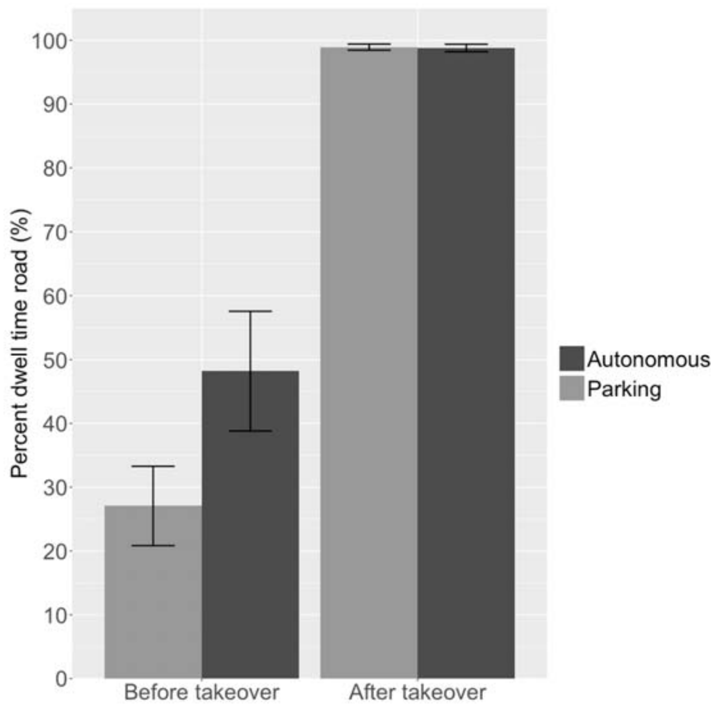

Figure 9. Percentage of time spent looking at the road before and after the take-over for both autonomous driving and stationary conditions.

As Figure 9 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 stationary 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%).

In rare occasions participants used the time looking away from the road other than watching the playing video. We registered two instances of this participant looking at a phone, one time during driving autonomously and one time while the car was stationary (Figure 10). Additionally, there was one participant that briefly inspected the cables on the steering wheel.

Figure 10. Participant looking at phone while the car was driving autonomously. The picture is captured from the eye tracker and the green dot represents the participants' gaze.

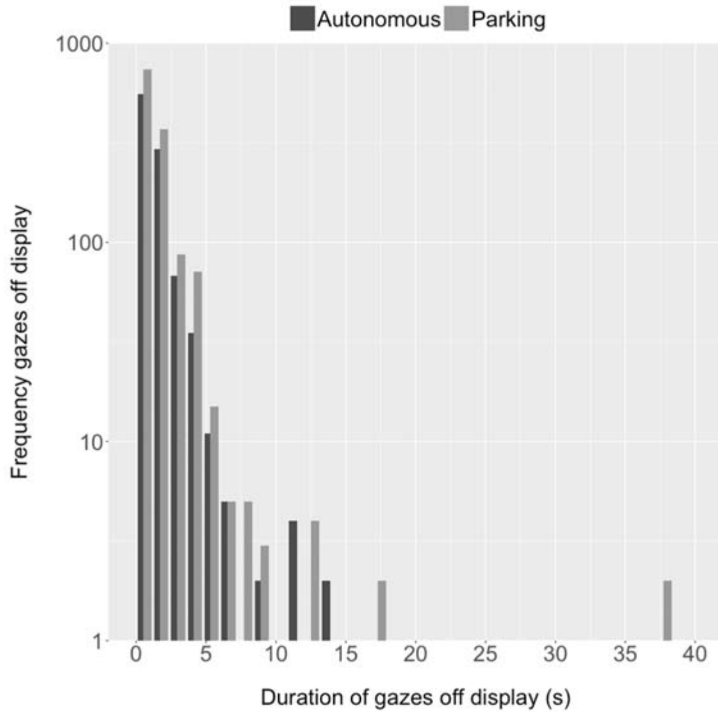

Figure 11. Histogram of the duration of gazes off the road before the take-over. The y-axis is in log scale.

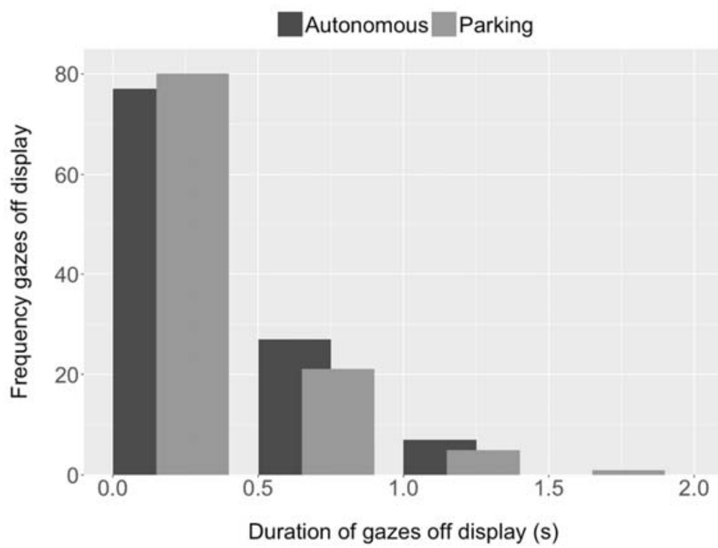

Figure 12. Histogram of the duration of gazes off the road after the take-over.

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 11 and *after* the take-over in Figure 12. 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 = 9.3, SD = 15.3), as can be seen by the higher frequencies in Figure 11 compared to Figure 12 (note that Figure 11 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, $t(10.1) = 39.76$, $p < .001$.

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 11 (before) compared to Figure 12 (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 stationary 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

Results

The results of the current study show no differences in gaze behavior and driving performance when starting to drive after being stationary compared to taking over after driving autonomously. 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 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 [34] argues, the take-over time primarily depends on cognitive processes and not motor processes. This indicates that the cognitive load for taking control after autonomously ng and starting with driving after parking seems to be similar with the current environment. Previous studies [6,25,34,35], that yielded similar take-over times, confirm our findings that the take-over time is not strongly influenced by previous distraction. Nevertheless, those studies showed that the quality of the take-over is worse after higher distraction before take-over.

Although we found no behavioral difference between the two conditions after taking over, there was a difference in eye-gaze behavior before the take-over. Participants looked away from the road significantly more when the car was stationary compared to when driving in an autonomous car, before taking over. However, in both conditions there were at least some glances at the road. Whether this is 'enough' to maintain the situational awareness during autonomous driving will depend on context. Around 50% of the time drivers did not look at the road, 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 NHTSA guidelines [13], this would significantly increase the crash-risk in non-autonomous driving. However, whether this would also increase risks for autonomous driving remains an empirical question.

The percentage of gazes towards the road center over time is in agreement with the results of Merat et al. [22]. There is a lower percentage right at the switch to manual control and consequently a stabilization (see Figure 8). The general percentage turned out slightly higher in the current study. This might be due to the absence of mirrors, other traffic and road signs. The focus towards the center shows no difference between driving after being stationary and taking over after driving autonomously. This suggests that the amount of distraction is similar in both conditions [11,32].

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 relatively high compared to previous research [15,21]. 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.

Implications

The results cannot confirm the hypothesized adaptation that could have caused a persisting engagement in distraction after taking over from an autonomous vehicle. This suggests that the well-studied take-over quality [4,6,7,22,25,33,35], which is found to be lower when taking over after distraction, is probably not affected by the discussed moving-vehicle adaptation but rather by just lower situational awareness, which is caused by simply not paying enough attention to the road before the sudden take-over.

With the results in mind, car manufacturers and infrastructure legislators trying to improve safety of autonomous vehicles do not have a direct need to focus on addressing adaptation to a moving vehicle considering distraction. Drivers show to be proficient to disengage from any distraction themselves when necessary, even when taking over from an autonomous vehicle. This does not mean that drivers are fully ready to perfectly take over with full attention to the driving task, as other studies have shown by assessing take-over quality [4,6,7,22,25,33,35]. It is still important for manufacturers, legislators and other involved parties to solve problems such as the lowered situational awareness during unexpected take-over situations.

LIMITATIONS

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

The different engagement in the distraction before take-over might influence the engagement after take-over. Nearly twice as much gazes towards the distraction while the car is static could result in stronger engagement after take-over, in contrast to the autonomous driving trials where the engagement towards distraction is already lower before take-over. If the initial engagement influences the engagement after take-over, it can even counteract the hypothesized adaptation. In future studies about adaptation it would be important to ensure that the initial engagement towards distraction is on the same level for all conditions to isolate the adaptation effect.

The experiment environment can be considered as an ideal situation with a straight risk-free road without other traffic. To initially reveal differences between the two conditions the experiment was kept simple for consistency but extended research with different environments and distraction types has to be done before generalizations can be made.

The two minutes of watching the distraction during autonomous driving or parking is relatively short compared to other studies about distraction in highly automated vehicles [7,22,34,35]. This might possibly have resulted in participants anticipating on the take-over and thus a lesser engagement with the 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 parking conditions, where starting to drive after being stationary is typically initiated by the driver with generally much more freedom. Our tested 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.

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 it 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 [30] 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 [7,22,35].

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. The findings do not show a diminished urge to stop any engagement in the distracting task when taking over from an autonomous driving vehicle. A lasting adaptation effect considering distraction in moving vehicles cannot be proven with the current results. Considering the limitations, we believe real world replications with diverse traffic and distraction situations would be necessary before valid generalizations about the absence of the effect can be made.

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