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Why Disable the Autopilot?

Hanneke Hooft van Huysduynen
Technische Universiteit Eindhoven
Eindhoven, The Netherlands
H.Hooft.van.Huysduynen@tue.nl

Jacques Terken
Technische Universiteit Eindhoven
Eindhoven, The Netherlands
J.M.B.Terken@tue.nl

Berry Eggen
Technische Universiteit Eindhoven
Eindhoven, The Netherlands
J.H.Eggen@tue.nl

ABSTRACT
The number of systems in commercially available vehicles that assist or automate driving tasks is rapidly increasing. At least for the next decade, using such systems remains up to the discretion of the user. In this paper, different reasons why drivers may disengage the autopilot are investigated. This was done through a simulator study in which the system could drive fully automated, but where participants could also disengage the system. Qualitative data were collected about why participants disengaged the autopilot. The analysis of the data revealed six themes covering the reasons why participants disabled the autopilot: The speed maintained by the autopilot, the behavior of the autopilot in relation to overtaking other vehicles, onset of boredom, onset of sleepiness, lack of trust in the autopilot, and enjoyment of manual driving. On the basis of the results, design opportunities are proposed to counteract the tendency to not use automated driving systems.

Author Keywords
Automated driving; autopilot; reasons to disable; human factors; risky driver; calm driving; simulator study.

CCS Concepts
• Human-centered computing~HCI design and evaluation methods • ***Human-centered computing~User studies***

INTRODUCTION
Technology forecasters predict that in the future, vehicles as we know them nowadays will disappear. Intelligent systems will take over activities such as steering, accelerating and braking, creating automated vehicles in which the role of the driver gradually changes from an actuator to an operator, and ultimately to a passenger [9]. Ultimately, vehicles will be able to drive in all possible situations they may encounter, thus drive fully automated corresponding to level 5 of the SAE automation taxonomy [30]. In such vehicles driving controls will not be available anymore and the driver will not be able to regain control.

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The purpose of the development of automated vehicles is to increase the traffic flow, reduce traffic accidents as well as driver's workload, distraction, and drowsiness, to create safer driving environments and mobility for everyone, and enhance convenience and sustainability. As long as automated vehicles are not able to operate in all possible situations, the driver needs to regain control when the vehicle is not able to proceed by itself. According to the SAE automation taxonomy [30], intelligent systems that correspond to level 2 of automation, also known as partial automation, still require full attention throughout the driving task. Here, the driver is responsible for identifying situations where the system runs into its limitations. Level 3 automated vehicles do not require supervision. When the system runs into its limitations, it will issue a request to the driver to regain control. Given that the vehicles in either of those two levels still contain driving controls such as a steering wheel, throttle and brake, the driver also has the possibility to regain control of the vehicle when the behavior of the systems in the vehicle deviates from the desired driving behavior, even if the system does not run into the boundaries of the technology. The behavior of the intelligent systems may, therefore, influence the willingness of the driver to use the autopilot. Therefore, the targeted benefits may be jeopardized when an autopilot is not accepted by drivers. This may not only affect the driver him/ herself but also other road users as well as the development of these type of systems in general. Knowing the reasons why people do not accept the automation may help to design the technology such that this tendency is suppressed.

In the remainder of this paper we will use the term 'autopilot' specifically to refer to intelligent systems that still require full attention throughout the driving task (level 2). Most vehicles with assisted and automated functions that are commercially available nowadays are partially automated vehicles, demanding continuous attention and requiring human intervention if needed. In this paper, reasons for drivers to disable the autopilot and regaining control without an objective need to take the control back are investigated. This is done through the analysis of qualitative research data gathered during a driving simulator study in which people drove in a vehicle that was able to drive in an automated manner, but required the driver to continuously monitor the system and surroundings. The aim of this paper is to create a better understanding of possible reasons why drivers may disable the autopilot function without there being a clear need to do so, so that the autopilot function can be improved and the users' willingness to use it may increase.

RELATED WORK

Levels of automation

The Society of Automotive Engineers (SAE) [30], has defined six Levels of Automation (LOA), ranging from 0 to 5, based on technological aspects of (a combination of) intelligent systems in vehicles.

Level 0 is defined as no automation as the driver controls the entire driving task, perhaps with the help of supportive functions as, for example, ABS. Most of the vehicles that are on the roads today can be categorized into this level. However, advanced driver-assist technologies, corresponding to level 1, *driver assistance*, are becoming more common. This level of automation involves one specific function that either, for example, keeps the vehicle in the lane or maintains a safe distance from other vehicles. Taking it one step further to level 2, *partial automation*, at least two primary control functions are working in unison, controlling, for example, both the position of the vehicle within the lane and the distance towards other vehicles. Perhaps the best known example of a vehicle at level 2 is the Tesla Model S. The autopilot of the Tesla Model S [43] makes use of multiple control functions, using adaptive cruise control to maintain the correct distance and an auto-steer function to stay within the lane in combination with assisted lane-change function to change lanes when the indicator is activated and it is safe to change lanes. When using the Tesla's 'autopilot' the driver must continuously monitor the situation and be prepared to regain control at any moment. This is the key characteristic of level 2. Vehicles categorized as level 3, *conditional automation*, enable the driver to delegate full control to the vehicle within specific driving conditions or environments without the need to continue monitoring the system and surroundings until the system requests to intervene. Audi introduced the first commercially available vehicle in level 3 [44]. Volvo started the 'Drive Me' project [45] in which customers use Volvo XC90s to drive fully automated on specific roads within Gothenburg without the need of supervision, corresponding to level 4, *high automation*. If the system requests an intervention and no response is recorded, the system should be able to handle critical situations without compromising safety. At the highest level, level 5, *full automation*, vehicles should be able to fully control all the primary functions of driving for an entire trip. Examples are the Waymo's car [46] and the Daimler Smart EQ concept [47], which are fully automated vehicles in which a driver is no longer needed.

Challenges and troubles using partially automated vehicles

As mentioned by Casner et al [7] the transition towards fully automated vehicles will be difficult for drivers, especially for partially automated vehicles in which automation is both incomplete and imperfect, requiring the driver to continuously monitor the system to be able to intervene and regain control. The driver will have to cope with different types of challenges when driving a partially automated vehicle, such as inattention, as drivers are more tempted to engage in secondary tasks [20,41]. These challenges may have an influence on the willingness of drivers to use automated systems and can provide reasons for drivers to disable these type of systems.

Driving manually contributes to a better task-specific understanding [33] of the situation that is also known as situation awareness [11]. Engaging in secondary tasks may result in lower situation awareness compared to drivers who drive manually, which may lead to more difficulty in regaining control and maintaining safe driving. Strand et al. [35] conducted a driving simulator study supporting the notion that driver performance degrades when the level of automation increases. A meta-analysis done by de Winter et al. [41], showed that drivers who are engaged in secondary tasks when driving in highly automated settings have lower situation awareness compared to drivers who drive manually, which may create difficulties when the driver needs to regain control of the vehicle, and therefore may provide a reason to disengage automated systems. Having lower situation awareness may affect the willingness to intelligent systems.

The willingness to use new technologies or systems in vehicles depends on other aspects as well. A commonly mentioned aspect is trust. Drivers who gain more experience with an automated system will also gain more trust in the usage of that system [28] and therefore positively influence the willingness to use intelligent systems in vehicles. However, as drivers' trust in the automation increases due to longer periods of impeccable performance, this may result in a decrease of attentional resources when driving a partially automated vehicle [7]. As trust influences the willingness to use automation and may provide a reason to disable automated systems, the large individual differences between drivers make predictions about the use more difficult [28].

Multiple studies looked into the transition between automated driving and manual driving and how to maintain driver availability for regaining control when needed [5,16,26]. Mok et al. [26] investigated the time needed to regain control of a vehicle when being engaged in the secondary task of playing a game on a tablet during automated driving. They found that the majority of the drivers needed 5 or 8 seconds to regain control in order to proceed safely. Johns et al. [16] looked into the idea of shared control using haptic feedback through the steering wheel. Correct support for transition between manual and automated driving may support drivers to continue using automated systems

Brown and Laurier [6] analyzed multiple recordings of Tesla's 'autopilot' indicating some of the troubles drivers may encounter when using the autopilot. An example is that a driver had to intervene as the autopilot followed the edge-markings resulting in taking the exit instead of driving the intended route. The troubles with the Tesla's 'autopilot' mentioned by Brown and Laurier [6] are related to the technical limitations of the system, requiring drivers to regain full control over the driving tasks. In the current paper, the human perspective is explored, investigating the different reasons drivers may have to disable an autopilot function in their vehicle when the situation does not require them to regain full control over the driving tasks.

Driving Styles

Drivers differ in their driving style [15,37], which includes the choice of driving speed, headway, overtaking of other vehicles, the tendency of committing traffic violations, attentiveness, and assertiveness while driving [10,40]. As drivers differ in their driving styles and attitude towards driving, this may influence the drivers' decision to disable an autopilot function in their vehicle even when there is no need to intervene. Hooft van Huysduynen et al. [14] looked into different questionnaires to determine a person's driving style. Six driving styles could be identified: Angry, Risky, Anxious, Dissociative, Careful, and Distress-Reduction driving style. The current study focuses on Risky / Thrill Seeking and Careful / Calm driving style, with the goal to investigate whether and why people with different driving styles disable the autopilot when there is no objective necessity to regain control.

METHOD

A study was conducted in a driving simulator. The simulator used in this study is a medium-fidelity fixed based simulator designed and manufactured by the Dutch company Green Dino BV. The simulator consists of a car seat, a Ford steering wheel, indicators, ignition key, pedals, a gear lever and a handbrake. The renderings are visualized on three 32 inch screens and the mirrors and dashboard are part of the 3D renderings. The driven speed and activation of the autopilot are logged by the simulator at 20 Hertz. In this study the vehicle made use of an automatic transmission.

Figure 1. Driving Simulator

The scenario (see Figure 1) consisted of a two-lane highway with mixed traffic, where, at certain moments, the traffic was a little heavy but there were no congestions. The vehicle used in this scenario had the partially-automated driving ability through the use of the autopilot. The autopilot function could be turned on or off by pressing a button located next to the handbrake, and it could also be deactivated by hitting the brake. When the autopilot was activated, the vehicle took over the task of driving, leaving the driver to only monitor the system. In the autopilot setting the vehicle controlled all aspects of driving including changing lanes and overtaking other vehicles. In this mode, the steering wheel moved along with the movements of the vehicle. The autopilot function used in this scenario can be categorized as level 2 of the SAE classification as participants were required to keep their attention focused on the driving task and to continuously monitor the system and the surroundings. This level is typical for currently available autopilot functions in vehicles such as the Tesla. As it is level 2 automation, the autopilot function is not completely perfect and therefore requires the full attention of the driver to intervene when needed. At certain moments the autopilot reduced the speed of the vehicle to around 80 to 90 km/h in order to give phantom traffic jams building up further down the road the opportunity to dissolve [31]. This could happen at moments when a minimum amount of traffic was around; no reason for the adjustment in speed was communicated to the driver.

The data for the current analysis were collected in the context of a study that aimed to investigate the effect of personalized soundscapes on participants' willingness to use automation [submitted]. These soundscapes were activated when the autopilot was enabled. The results did not provide conclusive evidence that the soundscapes used resulted in a better driving experience and in an increase in willingness to use the autopilot. As no conclusive answers were found that more personalized soundscapes influenced the willingness to use the autopilot, the current analysis zoomed out again and investigated alternative reasons why drivers may disengage the autopilot not related to the soundscape.

Participants

People were asked to participate in a driving simulator study concerning automated driving by completing a pre-evaluation questionnaire. This pre-evaluation questionnaire asked for demographic data and described a concrete scenario and eight different personas representing different driving styles, four of which represented calm/careful driving styles and the other four represented risky assertive driving styles [14]. Respondents were asked to imagine that it was a Thursday morning and they were in their vehicle driving to work. They were driving on the highway in mixed traffic, it was a busy road but there were no congestions. Then they were asked with which of the eight personas they identified themselves most for the given scenario.

The results of the pre-evaluation questionnaire were used to assign participants to one of the two driving styles, one the more assertive/risky driving style and the other the more calm/careful driving style.

Forty-four participants participated in the study, forty males (90.91%) and four females (9.09%), aging between 18 and 59 years (M=26.32, SD=6.92). The participants received a €10 gift card as a compensation for their time. Of the 44 people participating in this study, 28 participants (of whom two were women) were categorized as calm drivers and 16 participants were categorized as risky drivers.

Procedure and Measure

After signing the informed consent form participants were asked to take a seat in the driving simulator. The first part of the session was a training phase that allowed the participants to get familiarized with the simulator and its behavior as well as the use of the autopilot function, which controlled the vehicle until the function would be disabled by the driver. The aim of this part was that the participants would create a full understanding of how the simulator works, meaning that they had to drive both with and without the autopilot enabled. The participants were instructed that an autopilot system was implemented, allowing the vehicle to drive by itself when the autopilot was activated. It was mentioned that the autopilot could be activated and deactivated through a small button next to the handbrake and by hitting the brakes the autopilot would also be deactivated. This session took around twenty minutes on a two-lane highway with mixed traffic (See Figure 1.)

Before the start of the main part of this study, the participants had a five-minute break in which the system was reset and a brief explanation was provided to the participants. They were told to imagine they were sitting in their vehicle on a typical morning driving to their work. The participants were asked to drive in the simulator as if it was their own vehicle they use to go to work but now also making use of the autopilot function. They were told that the traffic rules were in line with the traffic rules as they apply on a typical highway in the Netherlands, including a speed limit of 120 km/h. The task was to monitor the system and the situation around the vehicle during the trip. Participants were allowed to disable the autopilot function when they did not agree with the behavior of the autopilot or felt uncomfortable, frustrated or not safe by using it. As the system had some minor issues with the trajectory for executing changing lanes, participants were instructed to ignore these issues by not letting them influence their decision to disable the autopilot. The trip on the highway took 20 minutes after which an alarm would ring, indicating that they could disable the autopilot if it was not already disabled and bring the car to the side of the road to make a safe stop. After this, the participants were asked to clarify the moments the autopilot was disabled during the session. They could do so by shortly describing the reasons why they disabled the autopilot function during the study (if they did) on a piece of paper.

The answers describing the reasons why they disabled the autopilot function during the study were documented and subjected to thematic analysis by means of affinity diagramming [21]: The different statements provided by the participants were repeatedly clustered by the authors based on similarity and the resulting clusters were labeled as themes.

FINDINGS

The autopilot was disabled on average five times per participant with a minimum of zero to a maximum of 13 times during the session. Sixty-four reasons were provided by the 44 participants why they disabled the autopilot during the trip. The reasons why participants disabled the autopilot function while driving were divided over six themes: the speed maintained by the autopilot, the behavior of the autopilot in relation to overtaking other vehicles, onset of boredom, onset of sleepiness, lack of trust in the autopilot, and enjoyment of manual driving. Table 1 shows the distribution of instances where the autopilot was disengaged over the different themes, as a function of the participants' driving style.

	Calm (N=28)	Risky (N=16)	Total
The speed maintained by the autopilot	9	9	18
The behavior of the autopilot	10	8	18
Onset of boredom	6	5	11
Onset of sleepiness	3	1	4
Lack of trust in the autopilot	9	1	10
Enjoyment of manual driving	3	0	3
	40	24	64

Table 1: Distribution reasons among driving styles

The themes will be elaborated further in the next part of this paper. For each theme we present the number of participants mentioning that type of reason, some quotes, the relation between the theme and the scenario, the relation to the literature, and how to design for that reason.

The speed maintained by the autopilot

In total, eighteen participants mentioned the drop in speed, below the maximum allowed speed without an obvious need, when the autopilot was activated as one of the reasons to disable the autopilot. This was done to momentarily drive manually in order to increase the driving speed.

"It was too slow… There was a possibility to go faster" (P6). "*It went below the speed limit slowing down my journey." (P22). "… slowed down for no reason." (P36) "I felt like the system was either driving too slow …."(P38)*

These remarks concerned cases where the speed of the vehicle was sometimes reduced to 80 to 90 km/h by the autopilot while the maximum speed was still 120 km/h. As explained in the Method section, this happened because the autopilot adjusted its speed in anticipation of a phantom traffic jam building up further down the road. However, this happened without providing an explanation to the drivers why the speed dropped.

Looking at the future, one of the ideas behind the use of the autopilot is that vehicles are able to communicate information such as direction, location, speed, deceleration and acceleration to other vehicles and the infrastructure. Communicating these aspects to other vehicles and the infrastructure allows vehicles to anticipate imminent traffic situations and subsequently adjust their own behavior and negotiate their actions with other agents (whether human or automated). This may, for example, result in reducing the vehicle speed in advance to prevent or diminish congestion further down the road. An example of such a system is an advanced version of Adaptive Cruise Control called Cooperative Adaptive Cruise Control (CACC) that is able to communicate between vehicles [31]. Schakel et al. [31] mention that CACC may reduce shockwaves by improving the traffic flow stability by reducing the speed. This may lead to a reduction of the speed without an obvious explanation. Lajunen et al. [18] indicate that skill-oriented drivers may get irritated and aggressive when certain traffic situations do not satisfy their expectations, which may lead to disabling the autopilot.

With respect to opportunities for design, providing information about why the system behaves in a certain way may enhance the willingness to use driver support systems [19]. For example, one might just explain the reasons why the speed of the vehicle is reduced. Or one might inform the driver about the gains and losses of their preferred way of driving compared to more adaptive driving in combination with information about the performed driving behavior. This can be done by showing that their behavior does not have a large benefit time-wise but may lead to worsening the traffic conditions. Another solution may be the use of illumination and/or haptic feedback to support situation awareness in situations that the role of the driver is changing towards supervisory control [4].

The behavior of the autopilot in relation to overtaking other vehicles

Eighteen participants mentioned that they disabled the autopilot because of the conservative behavior of the autopilot by reducing speed before overtaking trucks. Some mentioned explicitly that they disabled the autopilot to change lanes themselves in order to maintain the flow of driving and the driven speed. After overtaking the truck and changing back to the right lane the autopilot would be enabled again.

"If I saw the autopilot was very slow but I had the opportunity to overtake the vehicle in front" (P7). "Sometimes (in my opinion) taking over could have been done earlier so I would not get stuck behind a truck for a while because the autopilot only switches lanes when the approaching car is far away." (P8). "When overtaking trucks, the autopilot reduced speed while there was enough space between the vehicle and vehicles behind to overtake the truck" (P23). "When trucks are in the right lane, the autopilot did not overtake and drove below 80 km/h. During this time I took control of the vehicle" (P41).

During the study, the behavior of the autopilot could be experienced as unduly conservative by participants. The conservative behavior resulted in the vehicle always trying to go back to the right lane even when approaching a truck in the right lane. As a consequence, when approaching a truck in the same lane the speed of the vehicle would first be reduced before the vehicle would change to the left lane to overtake that truck.

Whereas human drivers drive their vehicles on the basis of their emotions and motivations [36], systems that take over parts of the driving tasks can be seen as sophisticated robots that maximize safety based on optimized logic [42]. However, the situation depicted here resembles the situation where a human driver using Adaptive Cruise Control (ACC) would not look ahead sufficiently, resulting in the ACC slowing down the speed before initiating the take-over maneuver. Currently, it is still unclear whether automated systems will be equipped with sufficient look-ahead capabilities to handle these situations satisfactorily. They are developed primarily with the aim to increase driver safety [2].

With respect to opportunities for design, a solution to overcome the gap between the behavior of intelligent systems in vehicles and drivers is the use of shared control. The control authority of the vehicle is, in this case, shared between the intelligent systems and the driver [1], allowing the driver, for example, to influence the acceleration of the vehicle. Another example of shared control is the use of haptic torque feedback on the steering wheel that can convey intent [16]. Shared control can provide the opportunity to improve safety as both the driver and the system can supervise [16]. An alternative to overcome the gap between the behavior of intelligent systems and drivers is to change the behavior of the system. For example, Volvo has an overtaking assistance with their adaptive cruise control (ACC). When the driver expresses the intention to overtake another vehicle through activation of the indicator, the ACC helps in accelerating the vehicle before changing lanes [39].

Onset of boredom

Eleven participants mentioned that the use of the autopilot resulted in feeling bored at some point. This resulted in disabling the autopilot as a way to counteract the boredom of just monitoring the system.

"Sometimes it is boring, by sitting and doing nothing in the car." (P5). "I felt bored at times, to sit idle. That's the one

reason why I disabled the autopilot" (P18). "When I felt bored sitting and just watching …" (P29). "Sometimes I felt bored and I wanted to do something." (P40).

The autopilot used in this study performed most of the driving tasks, leaving the participant to only monitor the system and surroundings. This required participants to maintain their attention to the driving tasks without the need to perform any of these tasks.

Boredom can be defined as "a state of relatively low arousal and dissatisfaction, which is attributed to an inadequately stimulating situation." [23:3]. In the context of driving, as the autopilot controls both the lane position and speed of the vehicle and drivers are still required to fully monitor the system, driving may be experienced as monotonous, with fewer tasks and lower workload [25]. Over time, this may reduce the willingness to monitor the systems and may lead to seeking other stimuli to reduce boredom and creating motivations to engage in secondary tasks like using a cell phone

With respect to opportunities for design, Diewald et al. [8] propose multiple eco-driving applications that make use of gamification. The game elements in these persuasive systems may enhance the motivation of drivers to use intelligent systems that support the driving tasks, as they provide additional tasks next to monitoring the system and surroundings. Mkrtchyan et al. [25] suggest that the use of alerts may be useful to sustain attention and thus counteracting consequences of boredom.

Onset of sleepiness

Four participants mentioned that the use of the autopilot induced sleepiness, leading them to disable the autopilot to increase the number of tasks to perform and thus their mental workload. By disabling the autopilot, participants avoided running the risk of falling asleep and getting involved in an accident.

"I felt that I was relaxed about the autopilot driving the car but I did not like the feeling of falling asleep and I preferred to not take such a risk and rather drive." (P4) "Once I felt sleepy with the autopilot. So I switched to manual to wake myself" (P13). "… It was actually making me sleepy" (P14) "…sometimes I almost fell asleep" (P42).

As already mentioned before, when the autopilot was activated during the study, the vehicle took over all driving tasks, leaving the driver to only monitor the system and surroundings.

When ADAS controls both the position of the vehicle within the lane and the speed in combination with the distance towards other vehicles, the driver's workload will be reduced. Reducing tasks for the driver to only monitoring the system may result in drowsiness or fatigue, which can be split into sleep-related and task-related fatigue [22]. Task-related fatigue can either be active or passive task-related fatigue. Active task-related fatigue is related to mental overload. Passive task-related fatigue can be related to mental underload [13] when, for example, the driving task is predictable or monotonous. Having the sole task of monitoring the system can be quite monotonous and as this reduces the workload, it can induce fatigue and decrease the performance of the driver in maintaining situation awareness [22].

With respect to opportunities for design, Miller et al. [24] indicated that drivers who were engaged in activities as watching a video or reading were less likely to exhibit drowsiness compared to drivers who only had to oversee the automated system. Several countermeasures can be implemented in vehicles against passive task-related fatigue. Gimeno et al [13] classified several empirical studies that have evaluated possible countermeasures. One of the countermeasures to prevent drowsiness, fatigue or inattention is the use of stimulation. This indicates that drivers might be stimulated through, for example, light, sound, cold air, music, or games to reduce fatigue while driving. Also, automated systems that share the control with the human driver may reduce driving fatigue and provide the opportunity to improve safety [16].

Lack of trust in the autopilot

In total nine participants, almost exclusively Calm drivers, reported reasons to disable the autopilot relating to trust or lack of trust in the autopilot.

"… Traffic was too dense and unpredictable at times, so I was unsure it would handle it" (P1). "Sometimes a car behind was too close." (P13). "There was a car approaching from the back very fast and getting close" (P19). "… I did not trust it enough to handle certain situations" (P38).

The behavior of other traffic in the scenario was not always predictable, similar to the behavior of drivers in real life. This was a reason mentioned by one participant to disable the autopilot. Another participant mentioned that a vehicle from behind was approaching at a higher speed and s/he was not sure how the autopilot would deal this, resulting in the disabling of the autopilot to make sure no accident would occur. One participant mentioned that another car came too close and therefore s/he disabled the autopilot. Three participants mentioned that they did not always trust the autopilot in handling certain situations and one participant was not comfortable when the vehicle was in a turn. Apparently, Calm drivers have a stricter interpretation of what is safe than Risky drivers.

For two participants the autopilot sufficiently fulfilled the expected driving dynamics as they did not disable the autopilot. They, therefore, trusted the autopilot to cope with tasks of driving by itself.

Trust is mentioned as one of the aspects of adapting and accepting automated technologies in vehicles by drivers as mentioned by Lee and See [19]. People tend to rely more on automation when they trust it and will more often reject the automation if they do not. Even if people do not trust the technology at first, by gaining experience with a new system that is reliable, users tend to gain more trust in the system [28]. People can also misuse or disuse automation [28]. Some people over-trust a system despite the system's inability to cope with the situation. This can result in misuse of the system creating unwanted or dangerous settings. Ignoring the capabilities and support of systems can be referred to a disuse of the system.

With respect to opportunities for design, the amount of appropriate trust and reliance a driver may have on the system is influenced by how well the capabilities of driver support systems are communicated to the driver [19]. Communicating the system's uncertainty may have a positive influence on the trust of drivers and the acceptance towards automation [3] as well as on situation awareness [34]. Verberne et al. [38] indicate that systems that share the driving goals of the driver and provide information are judged as more trustworthy and acceptable. Also, drivers who gain more experience with an automated system will most likely gain more trust in the usage of that system [28]. Next, it appears that Calm drivers have a different opinion about what is safe than Risky drivers. Taking into consideration the variety in driver's opinions about what is safe may also help to increase the acceptance.

Enjoyment of manual driving

Two participants mentioned explicitly that they disabled the autopilot to experience the thrill and enjoyment of driving related to manual driving, and a third participant wanted to make the driving more interesting again.

"To make driving more interesting" (P20). "… when I could enjoy the thrill of driving" (P29). "To experience the manual driving (enjoy driving yourself)" (P32).

These participants were all Calm drivers. However, the number is too small to conclude reliably that Clam drivers have a stronger desire for enjoying manual driving than Risky drivers.

As mentioned by Nordhoff et al. [27] it is challenging to gain the wow factor within driving when being driven by an onboard computer. Next to this, results of a questionnaire conducted by Kyriakidis et al. [17] showed that on average, their participants considered manual driving as most enjoyable. As the notion of autonomy is changing, the driving experience is changing along. During a study that explored how Adaptive Cruise Control (ACC) impacts people's driving experience [9], one of their participants said: *"… it feels like sitting on the neck (of a cat) just watching …*". This is in contrast to the experience when driving manually *"… a cat lying in the wait … when I drive the car, I become the cat to some extent …"*. Another participant mentioned holding the steering wheel more tightly compared to manual driving as this releases the tension of not using the pedals [9]. This study revealed that ACC creates a distance, a gap between the driver and the car. When driving with ACC activated the driving experience will change, which might be satisfactory for some but not for others.

With respect to opportunities for design, for drivers who pursue an exciting driving experience, the use of driver support system increases the decline in the experience due to the cautiousness and defensiveness of automated vehicles. This may be compensated for by intensifying visual, tactile and/or auditory sensations [29]. Schroeter et al. [32] argued that simulating risky driving or replacing risky driving triggers with alternative stimuli may reduce actual risky driving. Frison et al. [12] mentioned that automated driving lacks in provisioning joy of driving and proposes a hybrid interface combing the advantages of both manual and automated driving.

DISCUSSION

As discussed in the findings, previous studies have already delivered several insights regarding various aspects of the driving experience in combination with driver support systems. These studies independently modified specific attributes of the experience that led to specific findings. In contrast, in this study, these insights emerged from a general realistic driving task without focusing on any specific limitation of an autopilot system. This makes the current findings a relevant contribution to understanding the factors that influence users' interactions with the system and why they would disable the autopilot function even when it is not required by the limitations of the system.

As mentioned in this paper, some of the participants experienced the autopilot function as boring while for others it induced a more sleepy feeling. Both boredom and fatigue result in more inattentiveness which may cause problems when the system requires the driver to immediately regain control. Also, an increase in trust of the system can result in a decrease in attention towards the system, as the attention of the driver may shift towards secondary activities. This may cause dangerous situations when the driver is not fully aware of the system's status and the situation around the vehicle and has to drive manually again. Another aspect of level 2 automation is that these systems are perhaps both incomplete and imperfect, which requires drivers to sometimes intervene. When their attention is lower or absent, this may result in situations in which the vehicle makes an error that is not corrected by the driver, possibly resulting in a crash. Take for example the Tesla 'autopilot' that a driver uses on the highway, which correctly follows the road markings for quite some time. The driver gains more trust and starts to shift his or her attention to non-driving related activities, not noticing the construction works ahead. At some point, yellow road markings appear which are not recognized by the autopilot and the system keeps following the original white road marking, resulting in a crash into the Jersey barrier (road divider). These considerations raise the question of whether level 2 of automation is an appropriate level to implement in commercially available vehicles on a wider scale. A way out might consist of the different countermeasures discussed in this paper.

Limitations

It has to be taken into consideration that a driving simulator was used in this study. The fidelity of the simulator may have had an effect on the driving experience, and accordingly may have influenced how participants perceived the autopilot. In addition, the setting was artificial, so that the ride was not part of a real-life activity. Thus, it remains to be established that the same considerations will apply for use or disuse of the autopilot in real-life situations.

CONCLUSION

The number of driver support systems that are developed to increase safety and efficiency is increasing. These systems provide the opportunity to assign more and more driving tasks to the vehicle itself. The transition from manually driven vehicles towards fully automated vehicles will be accompanied by challenges and obstacles. The study described in this paper reported different reasons why participants disabled the autopilot function that was implemented in a vehicle in a driving simulator. The participants drove in a partially-automated vehicle for 20 minutes on a two-lane highway with mixed traffic. The different reasons why drivers would disengage the autopilot function categorized as level 2 of the SAE taxonomy were classified. The qualitative data gained from the driving simulator study described in this paper revealed six reoccurring themes: he speed maintained by the autopilot, the behavior of the autopilot in relation to overtaking other vehicles, onset of boredom, onset of sleepiness, lack of trust in the autopilot, and enjoyment of manual driving. The following part will elaborate further on these six themes, what they mean and how to design for.

The speed maintained by the autopilot was at certain moments reduced to 80 to 90 km/h without giving an explanation to the driver. This resulted in some of the participants disabling the autopilot. Providing more information on the motivation of the system's behavior may support the willingness of drivers to keep the autopilot enabled [19].

The behavior of the autopilot in relation to overtaking other vehicles resulted in a decrease in speed when approaching a truck before changing lanes. This could be seen as more conservative driving behavior. Intelligent systems in vehicles try to maximize safety based on optimized logic [42]. Next, these systems also comply with traffic rules even if this is not motivated by safety perspectives. Developing systems with better look-ahead or allowing for shared control between the system and the driver may support the willingness to continue the use of the autopilot [1].

Onset of boredom occurs through the monotonous task of monitoring the system. Participants mentioned that they disabled the autopilot to overcome the boredom as they were not allowed / able to perform other activities when the vehicle was driving by itself. Introducing gamification elements in the monitoring task may support the prevention of boredom when using automated systems [8].

Onset of sleepiness was also mentioned, leading participants to disable the autopilot, thereby increasing the number of tasks. A countermeasure against fatigue can be the implementation of extra stimuli [13] while using the autopilot.

Lack of trust in the autopilot was another reason to disable the autopilot. Trust is one of the aspects influencing people's willingness to use automated systems in their vehicles. By communicating the automation uncertainty and by taking into consideration the driver's opinions about what is safe, the trust of drivers and the acceptance towards automation may increase [19].

Enjoyment of manual driving and experiencing the thrill of driving was another reason to disable the autopilot. Automation may decrease the driving experience for drivers. This may be compensated through intensifying different visual, tactile and/or auditory sensations [29].

The current paper proposes several design opportunities to counteract the driver's inclination to disengage the automated driving system when there is no objective necessity to do so. Some of these will be explored in our further research.

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REFERENCES

1. David Abbink and Mark Mulder. 2010. Neuromuscular Analysis as a Guideline in designing Shared Control. In *Advances in Haptics*. InTech. https://doi.org/10.5772/8696
2. Bart van Arem, Cornelie J. G. van Driel, and Ruben Visser. 2006. The Impact of Cooperative Adaptive Cruise Control on Traffic-Flow Characteristics. *IEEE Transactions on Intelligent Transportation Systems* 7, 4: 429–436. https://doi.org/10.1109/TITS.2006.884615
3. Johannes Beller, Matthias Heesen, and Mark Vollrath. 2013. Improving the Driver–Automation Interaction. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 55, 6: 1130–1141. https://doi.org/10.1177/0018720813482327
4. Arie P. van den Beukel, Mascha C. van der Voort, and Arthur O. Eger. 2016. Supporting the changing driver's task: Exploration of interface designs for supervision and intervention in automated driving. *Transportation Research Part F: Traffic Psychology and Behaviour* 43: 279–301. https://doi.org/10.1016/J.TRF.2016.09.009
5. Mike Blommer, Reates Curry, Dev Kochhar, Rads Swaminathan, Walter Talamonti, and Louis Tijerina.

2015. The Effects of a Scheduled Driver Engagement Strategy in Automated Driving. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 59, 1: 1681–1685. https://doi.org/10.1177/1541931215591363

6. Barry Brown and Eric Laurier. 2017. The Trouble with Autopilots: Assisted and Autonomous Driving on the Social Road. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 416–429. https://doi.org/10.1145/3025453.3025462
7. Stephen M. Casner, Edwin L. Hutchins, and Don Norman. 2016. The challenges of partially automated driving. *Communications of the ACM* 59, 5: 70–77. https://doi.org/10.1145/2830565
8. Stefan Diewald, Andreas Möller, Luis Roalter, Tobias Stockinger, and Matthias Kranz. 2013. Gameful design in the automotive domain – Review, Outlook and Challenges. In *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '13*, 262–265. https://doi.org/10.1145/2516540.2516575
9. Kai Eckoldt, Martin Knobel, Marc Hassenzahl, and Josef Schumann. 2012. An Experiential Perspective on Advanced Driver Assistance Systems. *it - Information Technology* 54: 165–171. https://doi.org/10.1524/itit.2012.0678
10. James Elander, Robert West, and Davina French. 1993. Behavioral correlates of individual differences in road traffic crash risk: an examination of methods and findings. 113, 2: 279–294. https://doi.org/10.1037//0033-2909.113.2.279
11. Mica R. Endsley. 1995. Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 37, 1: 32–64. https://doi.org/10.1518/001872095779049543
12. Anna-Katharina Frison, Philipp Wintersberger, Andreas Riener, and Clemens Schartmüller. 2017. Driving Hotzenplotz: A Hybrid Interface for Vehicle Control Aiming to Maximize Pleasure in Highway Driving. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '17*, 236–244. https://doi.org/10.1145/3122986.3123016
13. Pilar Tejero Gimeno, Gemma Pastor Cerezuela, and Mariano Choliz Montanes. 2006. On the concept and measurement of driver drowsiness, fatigue and inattention: implications for countermeasures. *International Journal of Vehicle Design* 42, 1/2: 67. https://doi.org/10.1504/IJVD.2006.010178
14. Hanneke Hooft van Huysduynen, Jacques Terken, and Berry Eggen. 2016. Encouraging the Use of ADAS through Personalized Persuasion. In *Adjunct Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - Automotive'UI 16*, 105–110. https://doi.org/10.1145/3004323.3004335
15. Hanneke Hooft van Huysduynen, Jacques Terken, Jean Bernard Martens, and Berry Eggen. 2015. Measuring driving styles: a validation of the multidimensional driving style inventory. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '15*, 257–264. https://doi.org/10.1145/2799250.2799266
16. Mishel Johns, Brian Mok, David Sirkin, Nikhil Gowda, Catherine Smith, Walter Talamonti, and Wendy Ju. 2016. Exploring shared control in automated driving. In *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 91–98. https://doi.org/10.1109/HRI.2016.7451738
17. Miltos Kyriakidis, Riender Happee, and Joost C.F. de Winter. 2015. Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. *Transportation Research Part F: Traffic Psychology and Behaviour* 32: 127–140. https://doi.org/10.1016/j.trf.2015.04.014
18. Timo Lajunen and Heikki Summala. 1995. Driving experience, personality, and skill and safety-motive dimensions in drivers' self-assessments. *Personality and Individual Differences* 19, 3: 307–318. https://doi.org/10.1016/0191-8869(95)00068
19. John D. Lee and Katrina A. See. 2004. Trust in Automation: Designing for Appropriate Reliance. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 46, 1: 50–80. https://doi.org/10.1518/hfes.46.1.50_30392
20. Robert E Llaneras, Jeremy Salinger, and Charles A Green. 2013. Human Factors Issues Associated with Limited Ability Autonomous Driving Systems: Driver' Allocation of Visual Attention to the Forward Roadway. In *the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, 92–98. Retrieved December 8, 2015 from http://trid.trb.org/view.aspx?id=1363482
21. Bella. Martin and Bruce M. Hanington. 2012. *Universal methods of design : 100 ways to research complex problems, develop innovative ideas, and design effective solutions*. Rockport Publishers.
22. Jennifer F. May and Carryl L. Baldwin. 2009. Driver fatigue: The importance of identifying causal factors of fatigue when considering detection and countermeasure technologies. *Transportation Research Part F: Traffic Psychology and Behaviour* 12, 3: 218–224. https://doi.org/10.1016/j.trf.2008.11.005

23. William L Mikulas and Stephen J Vodanovich. 1993. The essence of boredom. *The Psychological Record* 43, 1.

24. David Miller, Annabel Sun, Mishel Johns, Hillary Ive, David Sirkin, Sudipto Aich, and Wendy Ju. 2015. Distraction Becomes Engagement in Automated Driving. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 59, 1: 1676–1680. https://doi.org/10.1177/1541931215591362

25. Armen A. Mkrtchyan, Jamie C. Macbeth, Erin T. Solovey, Jason C. Ryan, and M. L. Cummings. 2012. Using Variable-Rate Alerting to Counter Boredom in Human Supervisory Control. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 56, 1: 1441–1445. https://doi.org/10.1177/1071181312561406

26. Brian Mok, Mishel Johns, David Miller, and Wendy Ju. 2017. Tunneled In: Drivers with Active Secondary Tasks Need More Time to Transition from Automation. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 2840–2844. https://doi.org/10.1145/3025453.3025713

27. Sina Nordhoff, Bart van Arem, and Riender Happee. 2016. Conceptual Model to Explain, Predict, and Improve User Acceptance of Driverless Podlike Vehicles. *Transportation Research Record: Journal of the Transportation Research Board* 2602: 60–67. https://doi.org/10.3141/2602-08

28. Raja Parasuraman and Victor Riley. 1997. Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 39, 2: 230–253. https://doi.org/10.1518/001872097778543886

29. Jean-François Petiot, Bjørn G. Kristensen, and Anja M. Maier. 2013. How Should an Electric Vehicle Sound? User and Expert Perception. In *Volume 5: 25th International Conference on Design Theory and Methodology; ASME 2013 Power Transmission and Gearing Conference*. https://doi.org/10.1115/DETC2013-12535

30. SAE International. J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems - SAE International. Retrieved March 1, 2018 from https://www.sae.org/standards/content/j3016_201401/

31. Wouter J Schakel, Bart Van Arem, and Bart D Netten. 2010. Effects of Cooperative Adaptive Cruise Control on Traffic Flow Stability. *Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference on*, Idm: 759–764. https://doi.org/10.1109/ITSC.2010.5625133

32. Ronald Schroeter, Jim Oxtoby, and Daniel Johnson. 2014. AR and Gamification Concepts to Reduce Driver Boredom and Risk Taking Behaviours. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '14*, 1–8. https://doi.org/10.1145/2667317.2667415

33. Neville A. Stanton, Mark S. Young, and B. McCaulder. 1997. Drive-by-wire: The case of driver workload and reclaiming control with adaptive cruise control. *Safety Science* 27, 2–3: 149–159. https://doi.org/10.1016/S0925-7535(97)00054-4

34. Sonja Stockert, Natalie Tara Richardson, and Markus Lienkamp. 2015. Driving in an Increasingly Automated World – Approaches to Improve the Driver-automation Interaction. *Procedia Manufacturing* 3: 2889–2896. https://doi.org/10.1016/J.PROMFG.2015.07.797

35. Niklas Strand, Josef Nilsson, I.C. MariAnne Karlsson, and Lena Nilsson. 2014. Semi-automated versus highly automated driving in critical situations caused by automation failures. *Transportation Research Part F: Traffic Psychology and Behaviour* 27: 218–228. https://doi.org/10.1016/j.trf.2014.04.005

36. Heikki Summala. 2007. Towards understanding motivational and emotional factors in driver behaviour: Comfort through satisficing. In *Modelling Driver Behaviour in Automotive Environments: Critical Issues in Driver Interactions with Intelligent Transport Systems*. 189–207. https://doi.org/10.1007/978-1-84628-618-6_11

37. Orit Taubman-Ben-Ari, Mario Mikulincer, and Omri Gillath. 2004. The multidimensional driving style inventory--scale construct and validation. *Accident Analysis & Prevention* 36, 3: 323–332. https://doi.org/10.1016/S0001-4575(03)00010-1

38. Frank M. F. Verberne, Jaap Ham, and Cees J. H. Midden. 2012. Trust in Smart Systems: Sharing Driving Goals and Giving Information to Increase Trustworthiness and Acceptability of Smart Systems in Cars. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 54, 5: 799–810. https://doi.org/10.1177/0018720812443825

39. Volvo. Overtaking assistance with the Adaptive Cruise control*. Retrieved September 14, 2017 from http://support.volvocars.com/hk/cars/Pages/owners-manual.aspx?mc=v526&my=2016&sw=15w46&article=0a55ef938975ba62c0a8015148dad001

40. Robert West and Jane Hall. 1997. The Role of Personality and Attitudes in Traffic Accident Risk. *Applied Psychology* 46, 3: 253–264. https://doi.org/10.1111/j.1464-0597.1997.tb01229.x

41. Joost C.F. de Winter, Riender Happee, Marieke H. Martens, and Neville A. Stanton. 2014. Effects of adaptive cruise control and highly automated driving on workload and situation awareness: A review of the empirical evidence. *Transportation Research Part F:*

Traffic Psychology and Behaviour 27: 196–217. https://doi.org/10.1016/j.trf.2014.06.016

42. Nidzamuddin Md. Yusof, Juffrizal Karjanto, Jacques Terken, Frank Delbressine, Muhammad Zahir Hassan, and Matthias Rauterberg. 2016. The Exploration of Autonomous Vehicle Driving Styles. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - Automotive'UI 16*, 245–252. https://doi.org/10.1145/3003715.3005455
43. Autopilot | Tesla. Retrieved August 31, 2017 from https://www.tesla.com/autopilot?redirect=no
44. The new Audi A8 – conditional automated at level 3 | Audi MediaCenter. Retrieved March 2, 2018 from https://www.audi-mediacenter.com/en/on-autopilot-into-the-future-the-audi-vision-of-autonomous-driving-9305/the-new-audi-a8-conditional-automated-at-level-3-9307
45. Drive Me – the self-driving car in action | Volvo Cars. Retrieved August 30, 2017 from http://www.volvocars.com/intl/about/our-innovation-brands/intellisafe/autonomous-driving/drive-me
46. Waymo. Retrieved September 4, 2017 from https://waymo.com/
47. Here's how Daimler is evolving its tiny Smart car for self-driving - The Verge. Retrieved August 31, 2017 from https://www.theverge.com/2017/8/30/16226514/smart-vision-eq-electric-future-car2go