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Design friction in autonomous drive—exploring transitions between autonomous and manual drive in non-urgent situations

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Abstract

In the ongoing turn to automation, the growing trend towards the design of conditionally and highly automated vehicles (C/HAV) is evident. In a CAV, the driver no longer needs to partake in the driving. However, the vehicle might send a takeover request (TOR) when the CAV's system reaches its operational boundaries, i.e. a call for a transition from autonomous to manual drive. Previous research on TORs has focused on the context of urgent situations, e.g. hazards and unpredictable events. Furthermore, it has been noted that drivers' situation awareness (SA) deteriorates after being in autonomous drive. However, less is known about TORs in non-urgent situations. Motivated by this need, the study explores how design friction can serve as a guiding concept for transferring control between autonomous and manual drive in non-urgent situations to increase situation awareness. Design friction is defined as elements of interactions that steer attention and guides the driver to take informed decisions. The work resulted in prototypes that leveraged design friction as part of a takeover sequence. The proposed design was empirically evaluated in a fixed-base medium-fidelity driving simulator. The results indicated that the level of friction might have been too extensive, as some annoyance was expressed. However, participants claimed to feel calm and aware of their surroundings at the moment of regaining control of the vehicle. This suggests that design friction is a promising tool for guiding concept design to enhance transitions from autonomous to manual drive.

Keywords Design friction · Takeover request · Situation awareness · Interaction design · Conditionally autonomous vehicles

1 Introduction

In the ongoing turn to automation, conditionally and highly automated vehicles (C/HAV) are rapidly turning into reality. At this point, conditionally automated vehicles (CAV),

also referred to as level 3 (L3) by SAE [1], seem to be the next plausible step to be available for consumer vehicles [2]. According to SAE, CAVs have predefined operational design domains (ODDs) [1, 3]. The ODDs may be both static and dynamic and might vary for different CAVs. The ODDs depend on multiple factors such as geography, speed and environmental factors [1]. There is also an expectation for the driver to be available and receptive to a takeover request (TOR) upon the vehicles' request [4]. A TOR will be sent if the conditions for the ODD are not met, in the presence of a vehicle fault, or if the driver is detected as unavailable. According to today's legislation, the TOR must include multimodal warnings, namely tactile, visual and audio [5]. The driver has a limited time to respond to the TOR before a minimum risk manoeuvre (MRM) is initiated, leading to a full stop in the lane should the driver remain unresponsive. This procedure is aimed at minimising risks in traffic [5].

One big advantage of such a system is the possibility for the driver to engage in other non-driving-related tasks (NDRT) such as relaxing, playing games and answering

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emails. To aid this development, new solutions should be explored to be able to easily move back and forth between manual and autonomous drive.

The automation of driving enables a new way of travelling where productivity and play can be part of the journey [6, 7]. However, until it is possible to fully replace the driver with automation, an interplay between driver and system is expected to take place and this interaction should be designed to ensure comfortable and stress-free transitions between the driver and the system. When a CAV reaches its operational limits a takeover request (TOR) may occur, requesting the driver to resume manual control of the vehicle. From an interaction design perspective, it is suitable to look at this interplay with the driver in mind, in other words applying a human-centred design approach to the issue. Moreover, CAV has been shown to decrease the driver's situation awareness (SA) [8, 9], which may make a TOR in an urgent situation difficult to manage [10]. It is further argued that the driver needs to be invited back into the loop with a sufficient time budget to regain SA and thus be able to take control of the vehicle in a paced and robust manner [8, 9, 11–13].

Design solutions for TORs within CAVs, i.e. to enable transitions from autonomous to manual drive, have been extensively explored in the context of time-critical situations [8, 10, 13–16]. However, less attention has been paid to non-urgent and non-critical takeovers. The focus on urgent transitions of control may be attributed to the desire to understand the drivers' response in critical situations to accurately dimension the most extreme situations. However, in the nominal operation of a CAV, non-urgent transitions are expected to be frequent. A non-urgent takeover could be when the vehicle can foresee where it will not be able to continue in the autonomous drive, for example, when approaching the end of a certified road or when there is known upcoming roadwork.

Accordingly, this research aims to explore design solutions to facilitate transitions between autonomous and manual drive for non-urgent situations leveraging design friction as a framework.

Design friction is a method used to force the user to break a certain chain of behaviour [17–19]. Design friction can appear both in physical forms, such as speed bumps [20], or in digital forms such as pop-ups [18, 20]. However, to the best of the authors' knowledge, design friction has not been paid much attention in the context of automated vehicles nor the transitions between autonomous and manual drive. With the research gap identified, the research question we are aiming to answer is “How can design friction be used to facilitate the transfer of control between autonomous and manual drive in non-urgent situations?”. We contribute to this research gap by exploring how design friction may be applied to a TOR. The aim is to move the driver from an

automatic to a reflective state of mind to enhance the transition between automated and manual driving.

In this article design, friction is defined as intentionally added elements of interactions to steer attention to get the user to take informed decisions. With the use of attractors, the aim is to direct the driver's attention to key driving information. We report on the use of design friction as a guiding design concept for engagement for operation in the context of automation, namely within CAVs. On a detailed level, it is explored how to design for interactions with a dynamic system in CAV. We aimed to create a TOR that would ultimately enhance the transition between automatic and manual drive by the addition of design friction before the situation becomes urgent and time-critical. In this article, it is assumed that the vehicle will be able to drive autonomously for up to 30 min. Thus, allowing the driver ample time to engage in a NDRT and to have enough time for a non-urgent takeover.

This paper offers two contributions: firstly, we illustrate engagement with automation through a design project concerning a takeover sequence in CAV. Secondly, we propose how design friction can work as a guiding concept and approach for this implementation. The article is structured as follows: the first section introduces the research area and related work. The next section describes the three theories that are the foundation of the design. The method and process are then described before the final design is presented, followed by results from the summative evaluation. The article ends with a discussion and conclusion.

2 Related work

As automation moves beyond professional domains, such as aviation, it is highly relevant to consider the public when designing autonomous systems [21]. As described by Fröhlich et al. [21], automation is finding its way into our everyday life. Research regarding automation has addressed topics such as trust [22], cognitive load [23] and comfort [24].

In this article, the focus is on an everyday context—the car and the activity of driving in a vehicle capable of automation. This article aims to contribute to such “everyday automation” [21, 25] and how TORs can be designed in relation to aspects such as SA [26] and design friction [20].

TORs within CAVs have been extensively explored in the context of time-critical situations resulting in urgent TORs, e.g. hazards and unpredictable events such as a stranded vehicle on the road or complex weather conditions such as fog [8, 10, 13–16]. De Winter et al. [27] estimated that around 200 experiments have been published about TORs. Many of the studies have focused on factors such as takeover time and takeover quality after receiving a TOR with a short time budget (between 5 and 7 s). Furthermore, they

estimated that 96% of the studies published up until 2018 were conducted in simulators. De Winter et al. argued that there is a need to move beyond this paradigm of research as there is little new to be learned. In their critique, they mentioned that there is remarkably little research regarding for example longer time budgets [27]. To contribute to novel insights, this study aims to look at takeovers in non-urgent situations where a longer time budget is provided.

A non-urgent takeover is a type of takeover that allows the driver to get back into the loop, both cognitively and physically, by allowing them enough time to raise their SA prior to being in charge of the driving task again [2, 28]. Based on the results from previous research regarding the lack of SA, it can be assumed that when being able to let go of the driving responsibilities for a longer period, raising SA will become even more complex. The area of interest for this research is the time window preceding the typical 7–8 s time budget used for transitions of control with higher criticality (see Fig. 1).

Previous research has been conducted exploring how fast drivers respond to takeover requests, as well as the driving performance after regaining manual control. This study will therefore not analyse the effect of getting the driver's attention or look deeper into the aftereffects on driving performance. Instead, the focus will be on how to use design friction and how it affects their takeover experience. This study aims to evaluate a design to facilitate the transition from manual to autonomous drive; we have looked at a variety of research regarding both theories and previous design solutions.

2.1 User-paced and system-paced interaction

Previous research has explored how user-paced and system-paced transitions affect driver performance after a takeover [29]. Eriksson and Stanton found that user-paced transitions could reduce the risk of accidents when returning to manual driving. They further argued that these benefits must be considered when designing new systems [29]. Eriksson and Stanton [30] found that it takes 1.14 to 15 s for a driver to respond to a system-paced TOR with a limited time budget;

however, the time when they were able to self-pace the transition was between 1.97 and 25.75 s. Furthermore, Walch et al. [8] mentioned that drivers can take control within 4 to 8 s. It has been suggested that drivers that are provided with a longer time from TOR to regain control have a higher level of control when going back to manual driving [8, 29]. The study by Eriksson et al. [29] showed that drivers who were told to regain control when they deemed it safe to do so after the TOR remained in a lateral position similar to when driving manually, regardless of what activity they engaged with prior to the TOR. The results from their study indicate higher levels of control than the studies they compared it to, where drivers had a shorter amount of time of around 5 to 7 s.

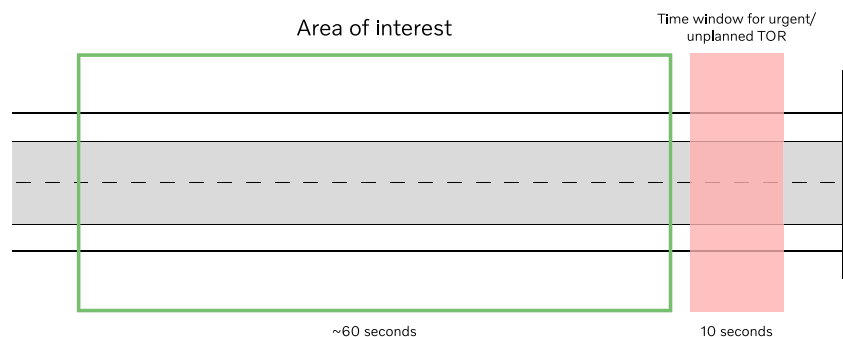
2.2 Situation awareness

Maintaining SA and keeping operators in the loop are well-established concepts in the areas of HCI (human–computer interaction) and safety research. There are different approaches for takeovers in high-risk domains, such as aviation and healthcare [31]. Clark et al. [31] identified 19 hand-over tools and techniques within these high-risk domains and created guidelines for designing with distributed situation awareness. Even though the research regarding TOR has been heavily focused on urgent and critical situations, there are studies that have looked at non-urgent situations [29, 30, 32, 33]. These have mainly been focused on TOR relating to NDRT and takeover times [34]. Knowing what NDRT the driver will engage in is difficult to say. Studies have been conducted investigating the subject; however, Pfleging [15] described it as a chicken-and-egg problem, meaning that it is hard to investigate the question since drivers have not been able to experience a C/HAV in their everyday lives yet.

2.3 Design friction

Design friction as a method is commonly used in technology such as websites and mobile applications, but it occurs in physical form as well [20]. It has for example been used in the context of privacy and security. In a

Fig. 1 The area of this research is the time before the time window for an urgent/unplanned TOR



framework created by Distler et al. [20]; it can be seen that intentionally added design friction can take on many different forms: nudges, warnings, attractors and security-enhancing interventions to name a few. However, all have the same goal, to help users behave more securely and maintain privacy, both in the digital and physical world. A nudge, for instance, can make a user reconsider their privacy settings before posting content publicly on social networks. In contrast, an attractor is more about steering the user's attention to parts that contain the most important information for a particular decision [20].

Some examples of design friction in the physical world are speed bumps on the road and rumble strips on highways. Speed bumps are commonly used to make drivers slow down in certain areas, while rumble strips are directing the driver back to the lane centre to avoid unsafe behaviour [20]. Similarly, Distler et al. [20] introduced a new concept: *security-enhanced friction*. It is a type of design friction that aims to decrease risk-taking behaviour, but without having the entire episodic UX affected. When imagining a UX curve, the security-enhancing friction will probably cause a negative spike in the curve when introduced. However, this should only be momentary. The importance lies in the fact that the UX recovers to acceptable levels after the friction (see Fig. 2).

Design friction has also been investigated in the context of increased perceived satisfaction. Mejtoft et al. [19] conducted a study where they compared using a mobile application for meditation with and without added design friction, to see how it affected users' satisfaction levels. The results showed that the participants preferred the mobile device prototype where the design friction was added. Furthermore, the participants found it more satisfying when they had a clear comprehension of the goal of the task, which was also the case with the prototype where the design friction was added. Moreover, a correlation was found between added design friction and increased satisfaction [19].

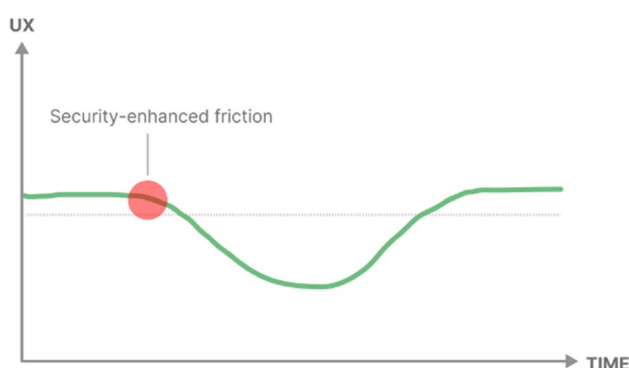


Fig. 2 Visualisation of security-enhanced friction UX curve developed by Distler et al. [20]

3 Theory

The design created in this study is to a great extent based on three main theories, where one builds upon the other: dual-process theory, design friction and situation awareness.

3.1 Dual-process theory

The dual-process theory of cognition (DPT) describes humans' decision-making as two different systems, one that has an automatic nature and one that is controlled and reflective. The DPT is likely based on the work by William James, who talked about the distinction between associative and true reasoning [35]. Kahneman's book "Thinking fast and slow" is a modern take on the DPT. Kahneman refers to the different systems as System 1 (S1), the automatic, and System 2, the reflective (S2) [36].

The main difference between the systems is that processes in S1 are characterised as unconscious, automatic and implicit, whereas S2 processes are conscious, controlled, analytic and reflective. S1 is at times thought of as an old process, in an evolutionary sense, where long-term memory is used, and attention is automatic [37]. This means that decisions can be made fast without any reflection as they are often based on heuristics. S2 on the other hand is relatively new from an evolutionary perspective, and it is a human trait [37]. S2 is what Kahneman refers to as slow thinking, and it is more dependent on working memory and controlled attention. S2 is more reflective, and decisions are often rule-based [36].

Driving a non-autonomous car requires significant effort during learning (S2) and becomes an increasingly automated skill with experience. For an experienced driver, the processing of information is unconscious and is followed by appropriate responses [38]. However, when resuming control of a vehicle, the process should not be too automatic as the driver may not have appropriately established their SA and thus may be required to respond to situations they have not had time to anticipate or prepare for. Design friction can help users switch out of the automatic and fast processes (S1) into a mode of thinking where they reflect upon what they are doing (S2) [39]. This is considered to help the driver become more aware of their surroundings and increase their SA.

3.2 Design friction

For many years, there has been a clear focus on designing frictionless and, therefore, effortless interactions, aiming to make the interactions more intuitive and easier to navigate [18]. What needs to be considered here is the context of where the design will appear. Babich [40] emphasised

how designers seem to be nearly obsessed with delivering solutions where you can get from A to B in the fastest and most efficient way. These effortless interactions can however have negative consequences, e.g. deleting something that was not supposed to be deleted or the user not being ready for the next planned move. Friction in design can help the user slow down to prevent and anticipate errors [41]. Design friction is intentionally added friction into a design, to create more mindful interactions between humans and machines [19]. It is a way to deliberately add “[...]points of difficulty encountered during users’ interaction with a technology” [17]. However, design friction is not about making the product less usable, but rather forcing the user to stop and reflect at certain, often critical points in the interaction which will result in more informed and thought-through decisions. Intentionally added friction in the right places will decrease mindless interaction where the user interacts automatically due to the design being fully intuitive [17]. Furthermore, Mejtoft et al. [19] emphasised the importance of considering the balance between good and bad design friction. What separates the good from the bad is whether the friction facilitates the interaction between the human and machine and does not come in their way of interacting [19]. Distler et al. [20] argued that a successfully added friction results in a behaviour that aligns with a particular user value, which in this case would be to make the driver ready for what is to come when engaging in driving again.

Design friction is often used as a general term and holds smaller subcategories. It is sometimes referred to as the facilitator of slow thinking, which is a term coined by Daniel Kahneman, intentionally slowing down how the user normally proceeds through a series of actions [19, 36]. *Micro-boundaries* are one type of design friction intended to slow the user down to enhance reflection and mindful interactions. It can be a small obstacle that prevents the user from going from one context to another without reflecting [17]. *Attractors* are another type of design friction, which aim to steer the user’s attention to the most important information in a particular situation. This can be done in multiple ways, such as using pure visuals or interactive elements [20]. In this study, the term design friction is used to describe an interruption that aims to steer the attention by interaction to get the user to take informed decisions. To be able to get to the point where the driver can take informed decisions, attractors can be used to steer the driver’s attention to key driving information valuable at that time.

3.3 Situation awareness

SA is defined as the perception of elements in the environment and the understanding of their meanings as well as their near future status [11]. In complex and dynamic environments, maintaining SA will therefore become more

difficult [26]. A lack of SA can lead to operators more slowly detecting issues, which in turn can be problematic since SA impacts both the base and the process for decision-making [26]. The notion of SA in automation is not a novel concept within human factors but has previously been investigated in fields such as aviation. However, it is an important aspect to bring to CAV, as many incidents within TOR are due to insufficient SA from the driver [42]. Since CAV allows drivers to engage in NDRT, the drivers will potentially end up out of the loop, reducing their SA [39]. There are some cognitive aspects needed to obtain SA, such as attention, perception, long-term memory and short-term memory. Furthermore, SA is likely to be affected by a person’s goals and mental models [26]. Attention is a necessity within human cognition as we are not able to comprehend all stimuli around us at once. Where our attention is directed is affected by, amongst others, our working memory and our perception. Attention is a limitation for SA [26] and in CAV; it should be considered how to get a driver’s attention and where to guide it in a TOR.

4 Method and process

This project followed the principles of human-centred design, namely understanding the user context, aiming to solve the root of the problem and iterating throughout the design process. Furthermore, the project was carried out following the Double Diamond framework, where the design process is visualised as two diamonds consisting of four main parts: discover, define, develop and deliver [43]. It is an iterative process that diverges and converges multiple times.

The design research process went through three iterations; see Fig. 3 for an overview. The first iteration started with a literature review and a survey to gather early inputs. During 4 weeks, articles were searched for concerning TORs in both vehicles and in other domains as well as literature regarding theories deemed relevant for the study, such as SA and the use of design friction. The survey related to expectations for autonomous vehicles was distributed online and was answered by 55 people. Brainstorming sessions to ideate on a first concept were held, and early low-fidelity prototypes in the form of sketches and wireframes were created based on the learnings. Early in the design process, a workshop was held together with six interaction design master students to work with the general user interface (UI). During this workshop, the low-fidelity prototypes were evaluated. Three personas and user journeys were then created based on the insights gathered up to that point. Furthermore, three semi-structured expert interviews were held with people within the field. The experts were invited to a shorter interview to talk about CAV and their various experiences within the area.

Fig. 3 An overview of the iterations and methods included in the design process

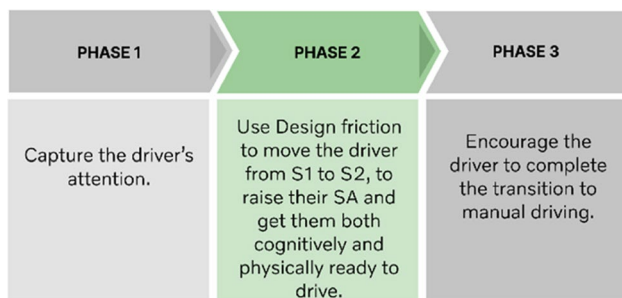
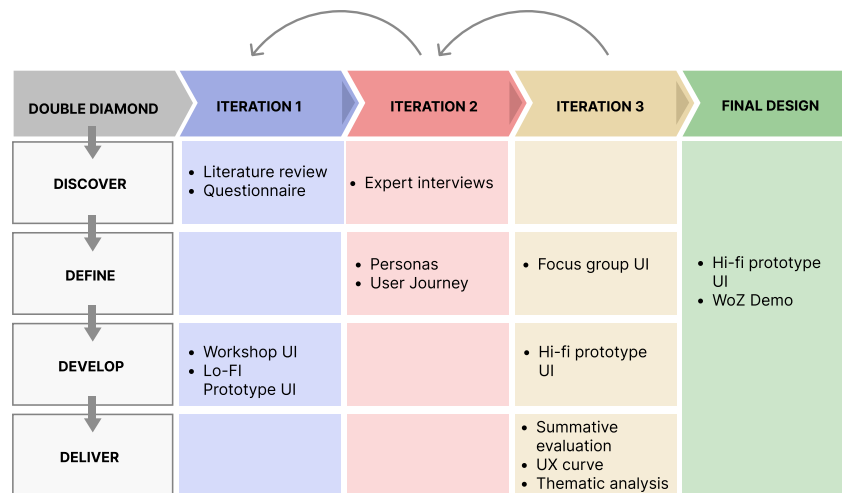


Fig. 4 An overview of the three phases of the takeover sequence; the highlighted phase is the researched area in this paper

In a later iteration, a focus group was put together with seven participants to discuss the development of the tasks. All participants involved in the focus group were master thesis students studying, amongst others, software development and design ergonomics. After the final iteration, a summative evaluation with six participants was conducted. The study concluded with an 'On the road evaluation' together with an expert in the field.

5 Final design and evaluation

The design presented in this article was developed iteratively and resulted in a takeover sequence rather than a request. It was early decided to call it a sequence, as more time allowed for several steps and not only the initial request. The sequence was divided into three phases, and each phase had a different purpose; see Fig. 4.

The aim of the first phase of the takeover sequence was to capture the driver's attention. As aforementioned, this has already been extensively studied and was therefore not analysed in this study.

The second phase was where design friction was applied, therefore serving as the focal point for this article. Design friction was used to move the driver from S1 to S2, to raise their SA and get them both cognitively and physically ready to drive.

The third and final phase aimed to encourage the driver to complete the transition to manual driving. This final phase was not intended as a research contribution but rather ensures the completeness of the transition phase, enabling the influence of design friction to be evaluated in context.

The experience utilising design friction was designed to be both self-paced, i.e. user-paced and system-paced, self-paced in the sense that the driver could choose what time to spend on the tasks (see tasks in Figs. 5, 6 and 7). There was no feedback on how much time the driver had to answer the questions. This decision was based on learnings from the UI workshop, where it was concluded that a timer would cause stress.

As can be seen in Fig. 5, the driver initiated the tasks and confirmed when they were ready for the next step. However, it was partially system-paced as the system controlled the task sequence. The driver was faced with a sequence of tasks, where the first one was to get back into a driving position. Once completed, they were asked to answer a set of questions about their surroundings, such as "what is the current speed of the vehicle?" (see Fig. 6). The rationale behind these tasks was to ask questions that connected to information relevant to manual driving and that would be easy to answer. The type of tasks also served as attractors to steer the driver's attention to key driving information, i.e. information valuable to know before reengaging in driving. The added friction was having the driver interact with the centre stack display (CSD), forcing them to stop and think when answering. The driver was however not forced to go through with the tasks immediately, but the vehicle's infotainment system could not be used while the tasks were

Fig. 5 Top: invitation to start the tasks “Prepare yourself to drive shortly. Autonomous drive is soon ending”. Bottom: prompt to move the seat to a driving position, “Move seat to driving position”

being completed. By adding friction at this stage in the take-over sequence, the driver was moved into a more reflective state (S2) where their SA was raised before taking charge of the driving task again.

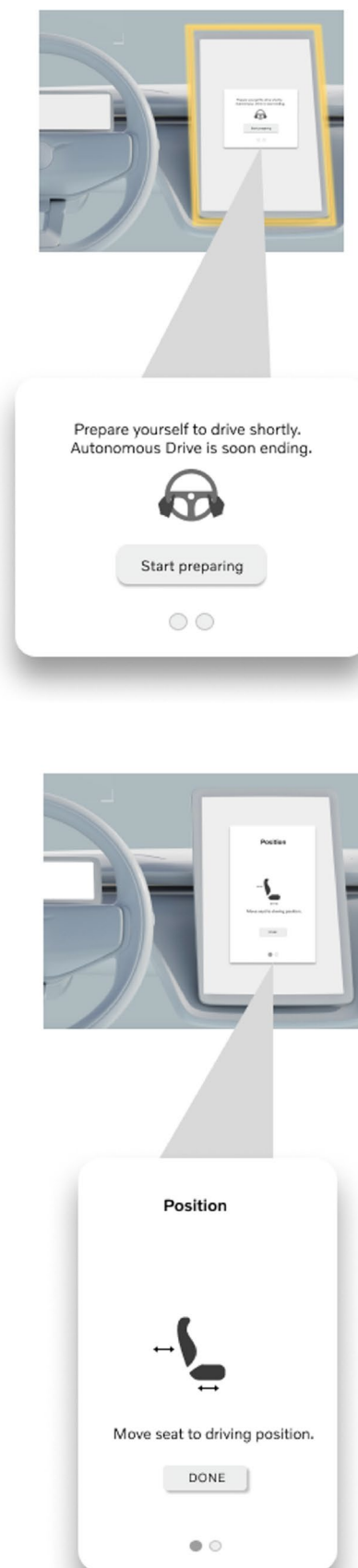
Moreover, the design friction was intended to be dynamic and adapted to what NDRT the driver was engaged with. This would then determine how many tasks they would have to go through and thus adjust the design friction accordingly, meaning that the level of friction should not be too high or too low.

5.1 Summative evaluation

During the design process, different low-fidelity and high-fidelity prototypes were made and evaluated. A summative evaluation of the final design was conducted through a user study. This study took place at Volvo Cars in Gothenburg. The study took around 30 min during which participants got to drive in a driving simulator for 15 min (see Fig. 8) and then fill out two evaluation scales and draw two UX curves. Each participant had a 45-min time slot for the study. Since there is a risk of feeling motion sick when driving in a simulator, the extra time was added if the participants needed to take a break. Driving simulators are widely used as an evaluation method for research and development of both safety and human factors [44]. Eriksson et al. validated the effects of transitioning research from a simulator to an on-road, and the results showed high relative validity [12].

Two evaluation scales were used to collect quantitative data, the Van der Laan acceptance scale [45] and the two-item system usability scale (SUS) [46, 47]. The Van der Laan scale measured the users' acceptance and was used as a benchmark to compare with future iterations of the design. The two-item SUS was used to see if the design was considered usable. The two-item SUS scale produces a score between 0 and 100. The average score is 68; a result lower than 68 would therefore indicate poor usability in the design. Finally, the participants filled in two UX curves that would also work as an aid for discussing their experiences during a debrief towards the end of the user study. One UX curve had the variables 'Stressed' and 'Calm', the other 'Aware of Surroundings' and 'Unaware of Surroundings'. Furthermore, observation notes were taken during the study. The observation notes and note-taking from discussing the UX curves were analysed through inductive thematic analysis.

To test the design, two scenarios were made to trigger two different conditions. Both scenarios started with the driver going to a friend's house. During Scenario A, the driver received a TED talk [48] that they watched for a few



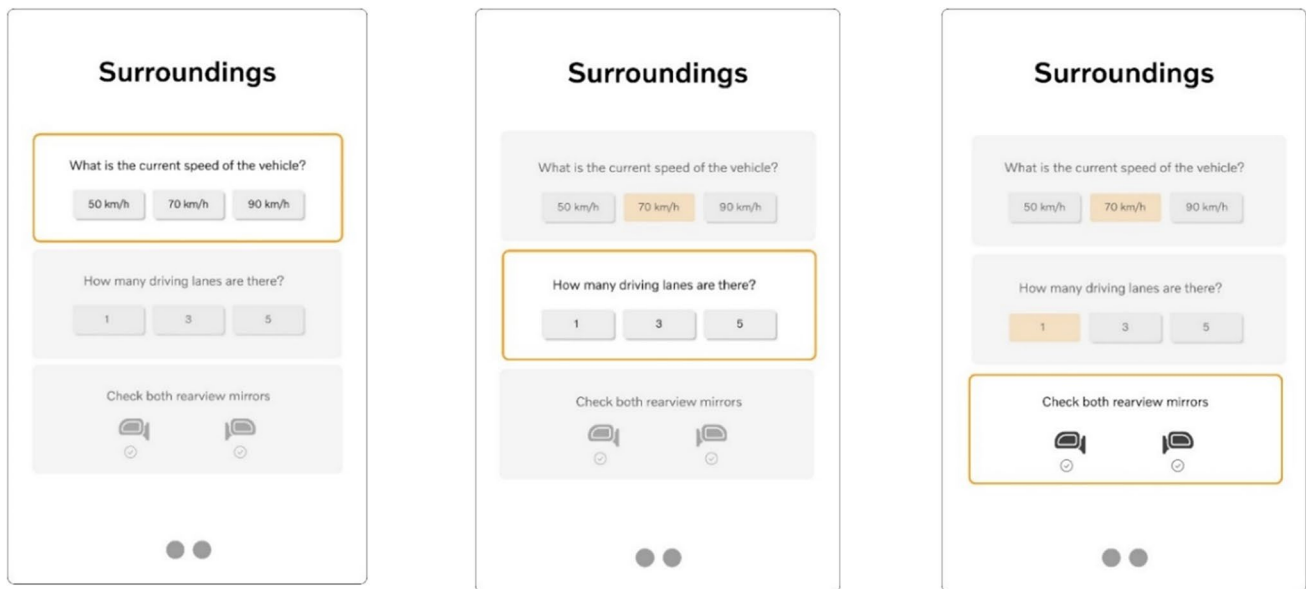


Fig. 6 Questions on the CSD regarding the driver's surroundings

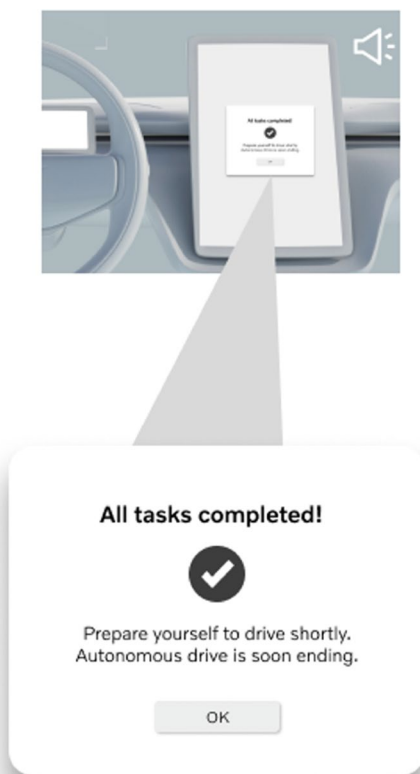


Fig. 7 Confirmation of completion “All tasks completed! Prepare yourself to drive shortly. Autonomous drive is soon ending”



Fig. 8 Participant stopped on the side of the road between scenarios

minutes on a smartphone provided to them by the facilitators. Since the TED talk distracted them from the road, they needed to complete three tasks on the CSD before being asked to regain control. In Scenario B, however, the driver was simply asked to look out the window to not get motion sick. For this scenario, the driver only had to complete one task on the CSD before completing the transition of control. For test setup, see Fig. 8.

5.2 On-the-road evaluation

To wrap up the design research project, the final design was implemented in a specially designed vehicle to demonstrate the design in a realistic setting (see Fig. 9). The vehicle was equipped to simulate a CAV through the WOz



Fig. 9 The vehicle used for the Demo Drive

Table 1 Results from the two-item system usability scale (1–100)

System usability scale	
Score	78.97

Table 2 Results from the Van der Laan scale

Van der Laan scale	
Usefulness	1.266666667
Satisfaction	1.208333333

method, allowing the driver to completely let go of control for a period of time while driving on a public highway in Gothenburg. CAV was simulated by having a WoZ driver controlling the car from the back seat. One expert from the expert interviews earlier in the process was invited to go through the experience. Both scenarios from the final evaluation were demonstrated in two sections where the vehicle could be in an autonomous drive for the longest time possible. The route consisted of two practice sections, four normal transition sections and two sections to demonstrate the design. In the car was the wizard driver, the expert and one facilitator.

6 Results

Results from the two-item SUS can be seen in Table 1, and results from the Van der Laan scale can be seen in Table 2. The average score for the two-item SUS is 68 points, which means that the takeover sequence was interpreted as usable with 78.97 points [46, 47]. Following the UX curves the participants had drawn during the debrief, it was possible to follow the entire experience of the takeover sequence. When starting with the tasks on the CSD, some participants expressed feeling stressed because they had to look away

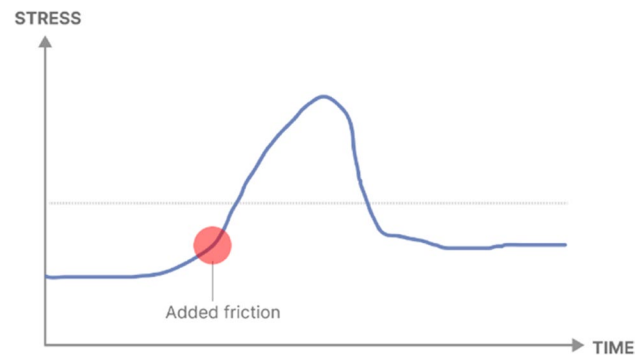


Fig. 10 Visualisation of one of the UX curves drawn from a participant regarding the level of stress

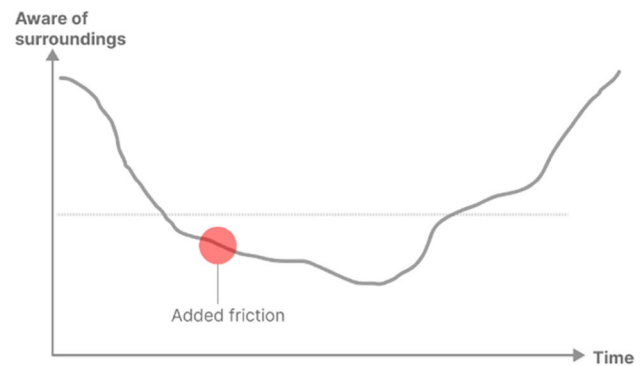


Fig. 11 Visualisation of one of the UX curves drawn from a participant regarding interpreted awareness of surroundings

from the road without knowing how long they had before the autonomous drive would end.

One participant said, “Tasks in CSD, one thing I started to think about was all the choices I had to make and I had no idea how much time I had”. However, another participant expressed it as more of a focus with the quote “The curve went up with the tasks, I was not stressed, but I was trying to answer it correctly. It was just more of a focus, I would not call it stress”. Furthermore, one participant expressed that the tasks made them think “about a checklist, like what pilots do”.

During the evaluation of the tasks, it was discussed that even though it might be annoying to be prompted to answer questions, it is possible that it would make you reflect on why. It was compared to the attention test that needs to be done when unlocking a Voi (a type of public electric scooter) at night.

One of the UX curves for stress can be seen in Fig. 10, and one for awareness of surroundings can be seen in Fig. 11. It should be noted that the UX Curves used during the evaluation had been adjusted from the curve introduced by Distler et al. [20]. Instead of the X-axis stating “UX”, we used the variables asking about stress and awareness of

surroundings. All participants regained control immediately after the tasks were completed, and they claimed to feel calm and aware of their surroundings, thus increasing their SA.

The observation notes from the evaluation debrief were inductively and thematically analysed. Concerning the fragments of design friction, five themes were found: unawareness, stress, focus on tasks, insecurity and awareness.

6.1 Unawareness

The theme of unawareness concerned participants expressing that they became less aware of their surroundings when they were introduced to the tasks in the CSD. For example, Participant 2 said that “At some point when all the messages came it almost took more focus from the road, especially with the tasks.” and expressed explicitly that they “[...] almost thought the tasks made me less aware.”

6.2 Stress

Stress was identified as a theme as it was part of many participants’ experiences, although at different levels. Stress was mentioned in relation to time, Participant 4 said that “I was a bit stressed that I have to solve several tasks.” whereas Participant 3 referred to the takeover: “I was a little bit stressed since I knew I was in the handover transition.”

6.3 Focus on tasks

During the debrief, participants mentioned focus when discussing the tasks. For example, Participant 5 said that “The curve went up with the tasks, I was not stressed but I was trying to answer it correctly. It was more of a focus, I would not call it stress.” Participant 4 reflected on where they had their own focus “[...] wondering if I focused that much on the surroundings or if I was more aiming at solving the tasks.” Furthermore, Participant 4 expressed a loss of focus on driving, “But I would say I lost focus on driving when I was given the tasks.”

6.4 Insecurity

Another theme discovered was insecurity. It relates to various kinds of insecurity, for example, Participant 4 felt unsure about the amount of time they had to complete the tasks: “[...] one thing I started to think about was all the choices I had to make and I had no idea how much time I had.” Participant 3 felt split in their attention “I was able to pay attention to the TED talk, but at the same time I was a bit split in my attention.” On the other hand, Participant 3 also felt some insecurity about how to practically complete the tasks, “That was nice, but I didn’t know if I were to tick the boxes on the last task.”

6.5 Awareness

The final theme identified was awareness. Participants expressed that their awareness fluctuated during their drive, all ending on a higher level after completing the tasks. Participant 2 said “[...] I had to look at all the lanes, so maybe it (the awareness) goes down but then up.” Participant 4 reflected on how counting lane lines affected their awareness and said “[...] I still counted lanes and that so it still makes me more aware so it [UX curve] goes up a little. As mentioned, the UX curve reached a higher level of awareness for all participants at the end of the drive. Participant 5 concluded that they “Ended of aware of the surroundings.”

7 Discussion—key insights and future work

Considering the novelty of the area, there is a lack of knowledge from real-life experience. From an interaction design perspective, there is no single design solution, and new ways of interactions should be explored. This design research project set out to explore new interactions by providing a longer time budget and using design friction to steer the drivers’ attention, to raise their SA prior to regaining control of a CAV. Although the results indicate that design friction may be used as an important tool in designing TORs, it is evident that there is plenty of research to be done to further cement design friction as part of human-centred CAV interactions.

7.1 Design

Many design decisions have been made to achieve a takeover that will not be stressful. To guide the driver in the takeover sequence, it can be seen as consisting of three phases, each with a different purpose and therefore different preconditions. The sequence, however, is limited as there is a time constraint for taking over even though the situation is non-urgent. In other words, there cannot be an ongoing interaction without an ending. As mentioned previously, the focus has been the part of the sequence where design friction was intentionally added, to dive deeper into how it can be used when regaining control of a CAV.

To add friction, the takeover sequence included several tasks. Something that came up during the focus group was that the UI of the tasks and the questions were seen as sterile and not very playful. As mentioned, one participant expressed that the tasks reminded them of a checklist. The reason for introducing design friction is a matter of ensuring the drivers’ awareness of their surroundings and preparing them for manual driving, not including playfulness. In other words, it is sufficient if the experience manages to engage the driver. With regard to the comparison of the attention test in a Voi, even if the test is passed, it serves as a reminder

that the user should reflect on their actions and consider their awareness. The tasks introduced in the CSD were not meant to be difficult to complete; like the Voi situation, it was meant to prompt the driver to reflect.

Furthermore, in the final evaluation, there were some concerns regarding the driver's interpretation of the tasks, such as when asking about the number of driving lanes. Would the driver look at the lanes in their own direction or would they look at both? The questions should be easy to answer as the aim is not to put the driver on the spot. The purpose of the questions is to break a chain of behaviour while raising their gaze and thus increase their SA and have them mentally switch to S2, the reflective thinking, in accordance with the DPT.

There is a fine line between creating a valuable experience and causing too much irritation when using design friction. This becomes especially important when using it as a guiding principle for transitions from autonomous to manual drive, as the driver should be in the right state of mind when being in control. An attempt to balance this was to adapt the number of tasks to what the driver was doing. Furthermore, to make sure the driver does not automatically answer the questions, which would defeat the purpose of getting them to the reflective thinking, it should be considered if the questions should vary. The working idea is to have them vary in order, as well as the fact that they are depending on their surroundings. Something that came to light during the final evaluation was that participants felt insecure when having to answer questions on the CSD while at the same time being informed that they would soon need to drive. They expressed the reason being that they did not know how much time they had. The reason for not including feedback on transition status was based on learnings from the first workshop that was held to explore UI solutions. Some participants expressed that a time indication would make them feel more stressed. It would have been good to spend more time exploring how to show drivers their time span for completing the tasks, without having them feel rushed, as the time aspect was a topic that emerged both in the UI workshop and during the final evaluation. Stress caused by a limit of time needs to recover to an acceptable level towards the end of the experience. As the design aims to use friction to facilitate a transition between automated and manual driving, it is undesirable to add to the sense of stress caused by the design in a situation that requires the driver to focus on the task.

7.2 Final evaluation

The aim of the design was to prepare the driver to be able to take back control with improved awareness of the situation in which they took over. This was done by aiming to raise their SA which has been shown in previous research to be a key aspect to maintain steady control of the vehicle after

taking over. SA was measured qualitatively by letting the participants fill in a UX curve. It was considered to provide value to let participants reflect on their subjective SA in this initial stage. Their subjective experience could be an important part of building trust in the system.

Furthermore, as previous research has discussed the importance of balancing the design friction [20], the participants were asked to draw a UX curve showing their stress level during the experience as well. This was done to give an indication of how they responded to the design friction. The two curves aimed at collecting different data and guiding the conversation during the debrief. In other words, they are not intertwined and should not be collectively analysed.

7.3 Results

Data from the study was collected in the form of two Likert scales (two-item SUS and Van der Laan), the drawings of UX curves as well as notetaking of the discussions. Both scales were only collected once and were answered as a joint expression of the two scenarios. This could be problematic as the two scenarios might have been experienced differently. However, as the study was not meant to compare the two scenarios and as counterbalancing had been used, it was considered good enough. The result from the SUS was 78.97 points, which is above the average score of 68 points. In other words, the takeover sequence was interpreted as usable. The Van der Laan scale on the other hand is often used for comparisons. In this case, the result can be used as a benchmark to later be compared to when testing future versions of the design.

This study explored how design friction can be used for transferring control between autonomous and manual drive in non-urgent situations. The design friction was assessed by having the driver interact with the system. When encouraged to take over, they were asked questions that required them to become aware of their surroundings and interact with the CSD. Had the tasks in the CSD not been there, it would have allowed the driver to simply take over without reflecting on what was happening in the surroundings.

In a similar fashion to being nudged to reconsider your privacy settings before posting content publicly on social networks [20], the design friction was implemented to urge the driver to become aware of the potential new surroundings and circumstances. From the moment the driver went from manual to autonomous drive until the moment the control shifted back again, much could potentially have changed. It is important to make the driver reflect and become aware of the new surroundings before reengaging in driving. As discussed previously, it was important to consider the balance between good and bad design friction, thus the balance between *helping* and *frustrating* the driver. The design friction aimed to make sure that it facilitated the interaction

between the driver and vehicle, rather than coming in their way. However, the final evaluation showed increased frustration and stress, similar to the drop in Distler et al.'s UX curve [20]. When compared, the curves look like they are opposite; however, this is due to the labelling on the X-axis as previously mentioned. A potential explanation for these feelings might have been that the design friction was too extensive. Instead of making the driver reflect upon their surroundings to become ready to drive, it was rather experienced as tasks that took time away from the possibility to focus on their surroundings. Some annoyance or stress would be considered acceptable for the purpose of the design if the overall UX recovers. As Distler et al. [20] discussed, the Security-enhancing friction may lead to a momentary negative effect on the UX curve, but it is important that the UX recovers to avoid disuse. As mentioned, in this study, the participants' curves showed the same tendency of dropping and recovering, although not recovering to the same level as prior to the design friction. Similar results from this study and Distler et al. [20] point towards using design friction to enhance awareness as a promising approach and should be applied when interacting with autonomous vehicles.

The research question was answered through design exploration and found that design friction shows promise in non-urgent takeovers. However, continuous work should be conducted to find a balance in the friction.

7.4 Engaging with automation through a takeover sequence

The definition of design friction in this study is intentionally added elements of interaction to steer attention to get the user to take informed decisions. By reaching a state where informed decisions can be made, the driver needs to move from S1 to S2. Research regarding DPT is nothing novel; however, introducing the way of thinking into the field of automation has not been explored. In using elements to support interaction, we hoped to encourage the users' interplay with the autonomous system. Results from the study showed that participants did in fact reflect more after being introduced to design friction. In other words, the results align with previous research regarding DPT even though there are no direct comparisons from studies regarding automation.

When engaging with automation, we found that the test participants felt insecure when having to answer questions on the CSD while being informed they would soon need to drive, as they did not know how much time they had. The design aimed to allow the drivers a self-paced takeover, meaning the system should not lead the timing of the transition. When engaging with automation, this led to a discrepancy between self-paced takeovers and feedback on transition status. These findings differentiated partly from what was expected based on previous research. Self-paced

transitions have been found to lead to takeovers where the drivers' driving performance is comparable to manual driving; however, the research has not covered levels of stress [8, 29]. A conclusion is that self-paced transitions might need to be accompanied by feedback from the system. The feedback could provide the driver with guidance to let them feel safe and trust in the autonomous system they are engaging with.

Our proposed takeover sequence contributes to engagement with automation. However, a longer takeover sequence that demands some sort of effort from the driver could deprive their time spent in autonomous drive. On the other side, as this study assumes the capability of autonomous drive for half an hour that should not be considered an issue. Furthermore, the compromise of time is necessary to avoid ending up in a situation with unnecessary time pressure. Lastly, it should be considered whether creating a transition where the driver claims to feel comfortable after regaining control of the vehicle could eventually lead to more time spent in autonomous drive, once again leading to further engagement with the system.

7.5 Limitations

The prompted questions in the CSD were designed to be easy for the users to answer and to be related to the vehicle's surroundings. However, the questions were not tested before including them in the whole experience. In other words, other questions might have impacted the users' experiences differently.

The questions were primarily text-based and not accompanied by symbols. This was an intentional decision as there was an idea of having the focus on the questions and not an interpretation of symbols. However, to reduce the stress caused by forcing the driver to look away from the road, adding symbols along with the text could have made the tasks perceived as more glanceable.

As mentioned, SA was measured qualitatively in the final evaluation by letting the participants fill out a UX curve regarding their interpreted awareness of their surroundings. In other words, it can only indicate their subjective SA. No quantitative data was collected at this stage of the study as the primary goal was to test how the users responded to the experience emotionally. Even though this measurement was considered valuable, measuring the driving performance after the takeover with quantitative methods, such as lane positioning and harsh braking, could have provided data about how well the design managed to create a takeover in which the driver felt comfortable. On the other hand, how you perceive your surroundings is subjective, and that should not be diminished. The ideal collection of data would have been to complement the subjective experience with objective measures.

7.6 Future work

Finding a balance between being transparent about the transition status without causing stress needs to be further investigated. We need to find a way to ensure the drivers that they are not in a hurry, while at the same time not causing stress by providing too extensive feedback on transition status.

Furthermore, SA should be measured in a quantitative way to ensure that the subjective SA matches the driving performance. One way of doing this could be to compare driving performance after the takeover sequence and compare it to a takeover sequence where tasks have been removed.

Moreover, it is important to come up with a reasonable level of how much design friction to use without risking ruining the overall UX. This would need additional testing, e.g. A/B tests comparing different levels of design friction. To increase the validity of the study, there should be more tests conducted in real traffic as well as testing for longer periods of time in autonomous drive.

Lastly, adding design friction to a takeover sequence might only be a part of a full experience. It should be explored how different parts of the sequence interplay, to create a holistic design, starting from getting the driver's attention and following through until manual control is regained.

The coming era of CAVs can come to change how we view everyday transportation altogether. There is much more to learn, and it is an exciting change to follow.

8 Conclusion

The future of CAVs is a complex area that is still relatively unexplored. Previous research has largely been focusing on urgent TORs in time-critical situations [8, 10, 13–16] and what modalities to use for those situations [4]. The lack of SA by the time the driver resumes control after an urgent TOR has shown issues such as the driver having difficulties with maintaining lateral and longitudinal control as well as harsh braking [8, 9, 13, 28, 29]. The purpose of this study has therefore been to investigate non-urgent TORs with the use of design friction, to enhance a more comfortable transition by raising SA. Since the assumption for this study was that CAVs will be able to drive for around 30 min or more in AD, there was space to move beyond the shorter time budgets used in the literature. As de Winter et al. [27] mentioned, there seems to have been a narrow paradigm in the area of TORs. This study was therefore conducted with the aim of widening the research and contributing to filling the research gap of implementing design friction in non-urgent TOR.

To the best of the authors' knowledge, design friction has not previously been explored in the context of autonomous vehicles. Design friction, DPT and SA have been the foundation for the final design. The design resulted in a takeover sequence

rather than a single request since more time allows for several steps. The takeover sequence is divided into three phases where design friction was added in the second phase. On a more general level, and based on this project, we suggest that design friction might be a valuable approach to consider when designing for transitions between automation and manual interaction.

We noticed how extending the time for the takeover sequence allowed the drivers to prepare to regain control at their own pace, i.e. a user-paced transition. However, it is important that the driver has an approximate estimation of how much time they have available. When designing for a comfortable and stress-free transition, it is of high importance that the driver is both cognitively and physically back in the loop when reaching the point of manual driving, with an increased level of SA. This first part of friction is to ask the driver to get back into the driving position, which enables them to physically get back into the loop. To cognitively get back in the loop, the driver should answer a few questions about the surroundings before moving on to regaining control. The number of questions can vary depending on what NDRT they are engaged with; in other words, the level of design friction will be dynamic.

As we move towards more autonomous solutions, we face the need for solutions that demand shifting between autonomous and manual modes of interaction. We suggest that we have provided both illustrative design solutions and conceptual work for how these transitions can be implemented.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical considerations Ethical considerations during this study were deemed sufficient as it followed the principles from the WMA Declaration of Helsinki; all participants had given informed consent; there was no risk of harm, and no one was being tricked. Furthermore, test participants were, at any time, free to cease their participation without any negative implications.

Conflict of interest The authors declare no competing interests.

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