UNIVERSITY OF GOTHENBURG

DEPARTMENT OF APPLIED IT

DRIVER ENGAGEMENT

User experience of static & dynamic interaction and engagement in Non-Driving Related Activities in Automated Vehicles - An experimental study

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Abstract

The rapid development of automation in vehicles is reshaping the role of the driver and consequently changing driver behavior. This study is based on the SAE level 4 of automation, i.e the autonomous vehicle (AV) can drive fully autonomously in a conditioned area. The driver does not need to monitor the driving and can instead fully engage in a non-driving related activity (NDRA). The purpose of this study is to examine user experience in relation to engagement in NDRA (video watching and lego building) as well as timing of the take-over requests (TOR). This includes investigating a holistic view of the experience in a take-over scenario. Participants of this study were divided in two groups, with static and dynamic time frames. Static time frame entailed that the TOR was issued at fixed times for both NDRAs, compared with the dynamic time frame where the TOR was presented at different times depending on which NDRA the participant was engaged in. The two NDRAs were in turn divided into high and low engagement. Engagement level in NDRA showed a clear effect of how the participant experienced the take-over scenario, while time frames did not. Participants showed a preference for the static time frame of TORs. However, preference of time frame did not depend on which time frame the participant experienced during the test. A main influence on how participants reasoned about the preferred timing of the TOR was attitudes towards AVs.

Keywords

Non-Driving Related Activities, Take-over Request, SAE Level 4, Engagement, Situational Awareness, Self Assessment Manikin, The Contextual Control Model, Take-Over Scenario

Acronyms

AV = Autonomous Vehicle

CL = Cognitive Load

COCOM = The Contextual Control Model

RCM = Russell's Circumplex Model

SA = Situational Awareness

SAM = Self Assessment Manikin

TOR = Take Over Request

Titel

Engagemang av förare: Användarupplevelse av statisk och dynamisk interaktion och engagemang i icke-körrelaterade aktiviteter i automatiserade fordon - En experimentell studie

Sammanfattning

Utvecklingen av automatiserade fordon formar om förarens roll och därmed förarens beteende. Denna studie är baserad på SAE nivå 4 av fordonsautomation, vilket innefattar att det autonoma fordonet kan köra självständigt i sitt begränsade område. Föraren behöver inte i detta scenario övervaka körningen utan kan helt engagera sig i andra aktiviteter s.k. non-driving related activities (NDRAs). Syftet med denna studie är att undersöka användarupplevelsen i relation till engagemang i NDRAs (bygga lego och videotittande) samt tidsintervall för förfrågan att ta över den manuella körningen (take-over requests = TORs) från autonoma körning. Syftet inkluderar att analysera deltagarnas attityder till autonoma fordon för att undersöka en helhetssyn på förarens upplevelse i ett scenario vid återtagande av manuell körning. Deltagarna i denna studie delades in i två grupper, statisk och dynamisk tidsintervall på TORs. Den statiska tidsramen innebar att TORs presenterades för föraren vid samma tidpunkter vid de två olika NDRAs. För den dynamiska tidsramen presenterades TORs vid olika tidpunkter beroende på vilken aktivitet föraren var engagerad i. De två NDRAs bedömdes att innefatta hög respektive låg nivå av engagemang. Resultatet av studien visar att engagemang i aktiviteterna påverkade hur deltagarna upplevde scenariot att ta över körning, medan upplevd tidsram inte påverkade. Deltagare visades föredra statisk timing av TORs men detta i sig påverkades inte av vilken grupp deltagarna blev indelade i (statisk eller dynamisk). Attityd gällande autonoma fordon visade sig istället ha stor påverkan på deltagarnas resonemang om design av TORs.

Nyckelord

Non-Driving Related Activities, Take-Over Request, SAE level 4, Engagemang, Situational Awareness, Self Assessment Manikin, The Contextual Control Model, Take-Over Scenario

Foreword

The workload for the design of the study and the literature review was divided equally among the authors. Elin conducted the interviews, while Sara was responsible for the autonomous drive conducted through the Wizard-of-Oz method. Elin illustrated results from the likert scales and SAM, while Sara coded and analyzed the interview data. The transcriptions from the interview were divided equally amongst the authors as was the rest of the work to write the report.

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1 Introduction

The rapid development of automation in vehicles is reshaping the role of the driver and consequently changing driver behavior (Gershon et al, 2021). This development of automation enables the driver to engage in tasks other than driving, so-called Non-Driving-Related-Activities (NDRA). This study focuses on the driver's experience in a take-over scenario in an autonomous vehicle (AV) of automation level 4. The user experience of a take-over scenario is investigated depending on two variables, NDRA and time frame of when the take-over request is presented.

1.1 Future driver behavior

The Society of Automotive Engineers (SAE) defines six discrete levels of vehicle automation outlined in appendix 1 (2019). It ranges from level 0 (no automation) that represents manual driving vehicles to level 5 (full automation), which represents self-driving vehicles in all conditions. The main difference between the levels of automation is the amount of control the driver is required to have of the vehicle. Before development of SAE level 5, conditionally automated vehicles (level 3) is of a more urgent research focus. Conditional automation implies that the vehicle is self-driving in a conditioned area which relaxes the driver from the driving role, but not completely. Transfer of control to the driver from the vehicle is still needed when the vehicle is outside of the conditioned area. (SAE J3016 , 2019). Drivers will shift into a more passive role in terms of vehicle control and monitoring, as vehicle automation increases and more control is transmitted to the vehicle (Gershon et al, 2021). This change of driver behavior opens up the possibility to engage in non driving-related activities (NDRA) such as watching a video or writing an email (Holländer & Pfleging, 2018). Where earlier studies have been focusing on the safety of a critical take-over (SAE level 3 and below), the research is now starting to shift from only having focusing on the safety of a take-over towards analyzing other parameters as well such as the pleasantness of a take-over. As we reach SAE level 4, will there no longer be any critical take-over situations but instead planned take-over scenarios. This shift from SAE level 3 to SAE level 4 creates new research areas, where pleasantness and user experience are of primary focus.

This study is based on the automation of level 4 which means that the driver does not need to monitor the driving and can therefore fully engage in a NDRA. When the AV reaches its driving limit, a TOR is issued which enables the driver to finish the performed NDRA and re-engage to manual driving. If the driver does not take over driving, the AV will stop the vehicle in a safe manner. The TOR will be presented to the driver far in advance until the critical takeover occurs and this is therefore considered a planned take-over request. This is the form of TOR that is used in this study and referred to throughout this work. This study was conducted as part of the research project RE-ENGAGE with Volvo, RISE and Smart Eye. The cross-disciplinary project aims to investigate user adjusted solutions for how to re-engage the driver from a NDRA to re-engagement in control of driving the vehicle.

1.2 Description of study

The focus of this study is to examine the user experience in relation to engagement in NDRA and the timing of the take-over request in AVs. This is investigated by examining participants' experience of the take-over scenario and how participants experience the interaction from the system to the driver in terms of TORs from the system to the driver. Two variables, NDRA and time frame of TOR, were selected to see if and how different conditions may affect the participants' experience. The NDRA in turn was divided into high and low engagement levels, to see how the two levels might impact the take-over scenario. Likewise the timing of when the TOR was issued was divided into two different groups which were dynamic and static. The dynamic group entails that the TOR was adjusted according to the NDRA the participant was engaged in, meanwhile the static group meant that the TOR were presented at the same time periods for both NDRAs. During the test participants were presented with only one set of time frame regarding the TORs, but experienced both NDRAs. The participants' experiences of the take-over scenario were then measured, which included the whole test procedure from the moment when the autonomous vehicle (AV) started driving in autonomous mode until the transfer of control when the participant took over and started driving manually. Theories used in this paper for designing the method of the study were Cognitive Load theory, Flow theory as well as Kahneman's System 1 and System 2. Whereas theories used for analyzing and interpreting the result were Russell's Circumplex Model of Affect, Self Assessment Manikin, Situational Awareness, Contextual Control Model and Grounded theory.

1.3 Purpose

The purpose of this study is to examine the user experience in relation to engagement in NDRA and the timing of the take-over request in autonomous vehicles. This includes investigating a holistic view of the experience in a take-over scenario. A takeover scenario refers to the transfer of control from vehicle to driver, and this transition occurs when the driver chooses to take over from autonomous drive to manual driving. A takeover scenario is considered to include the entire test round that the participant has completed for each activity.

1.4 Research Questions

R1) What is the participant's experience of the take-over scenario and what are the main factors that influence the experience?

R2) Were there any patterns of how the participants experienced the take-over scenario based on engagement in the NDRA?

R3) Were there any patterns of how the participants experienced the take-over scenario based on the time frame which the participant participated in?

2 Theory

Theories used when designing the method were Cognitive Load theory, Flow theory and Kahneman's System 1 and System 2. Whereas theories used for analyzing and interpreting the result of the study were Russell's Circumplex Model of Affect, Self Assessment Manikin, Situational Awareness, Contextual Control Model and Grounded theory.

2.1 Cognitive Load Theory

Cognitive load theory (CLT) suggests that the human working memory only can hold a limited amount of information. The CLT was developed by John Sweller 1980 and focuses on how we process information in learning and problem solving. Sweller et al states that an overload of information should be avoided to achieve utilized information processing (2011). In relation to autonomous vehicles, cognitive load often refers to the limited amount of cognitive resources that the driver has and how cognitively demanding a NDRA is (Engström et al, 2017 & Johns et al, 2014). This was addressed when designing the modalities for the take-over request.

2.2 Kahneman's System 1 & System 2

System 1 & System 2 was developed by Kahneman to describe how humans use two different systems when processing information (2011). System 1 is the information processing that is performed quickly and instinctively, it takes place unconsciously with minimal effort. System 2 is the information processing that is performed when rational thinking is required, conscious effort is mandatory and the system works slowly to be able to logically seek information and make decisions (Kahneman, 2011). These two systems were used to determine the cognitive load of the NDRAs used in the study.

2.3 Flow theory

Flow theory was initially developed by Mihaly Csikszentmihalyi in the 1970s (Csikszentmihalyi, 2008). Flow is a state of mind where you are completely absorbed by the activity you are pursuing which results in a pleasant experience. The theory states that in order to experience flow, the cognitive load required for the task should be just below your maximum effort (Csikszentmihalyi, 2008). This theory was useful when determining which activities to choose for the study design as well as the assessed engagement level.

2.4 Grounded theory

Grounded theory is a qualitative method regarding analyzing data sets and finding patterns based solely on the presented data, rather than starting from a specific theory (Walsh et al, 2015). The theory is a method based on three levels of categorization, where the first level is to collect the data and analyze it by coding and creating concepts. The second level regards categorizing these open concepts and the third level concerns creating themes from these concepts that have been found, which is done by constantly comparing the qualitative data. The found themes can thereafter be used to form a theory (Walsh et al, 2015). This theory was useful for providing a frame of reference when analyzing and constructing data from the interviews.

2.5 Situational Awareness

Situational awareness (SA) was originally developed by Mica Endsley and the concept is divided into three levels that is presented in detail below (1995):

Level 1: Perception of the elements in the environment

Level 2: Comprehension of the current situation

Level 3: Prediction of future status

Situational awareness has been greatly researched from the negative perspective of reduced SA when driving out of a critical point of safety. Attention and working memory are key factors of SA (Stanton et al, 2001) and although automation in vehicles is meant to reduce the workload of the driver, automation changes the role of the driver. Further this change of behavior shifts the drivers focus from the vehicle and road situation to NDRAs. For conditionally automated vehicles (CAV) the driver will be requested to take over control from automated driving at some point. If the driver has low or reduced SA and the vehicle is demanding the driver to take over in a critical scenario, the demanding change may pose problems for a safe transfer of control (Cunningham & Regan, 2015). Situational awareness was used as a framework when analyzing drivers' awareness of the surrounding environment when engaging in the two different NDRAs.

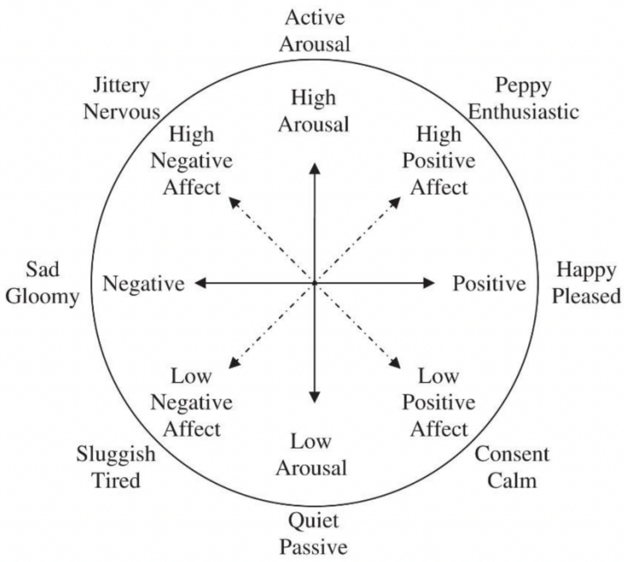
2.6 The Contextual Control Model (COCOM)

The Contextual Control Model (COCOM) was developed by Hollnagel 1993 to illustrate how control can be gained and lost through different actions, where context plays a key part in which actions one takes (ErikHollnagel). According to COCOM, sufficient time is one of the most important measures to take into consideration to achieve control. This includes having time to evaluate events, select and perform actions. Sufficient time also enables comprehension of the current situation. To attain control can be achieved in different ways, such as increasing the time frame, reducing the time needed to select actions or reducing the time needed to perform a certain action (ErikHollnagel). There are other measures than time to feel more in control, but given the scope of application, this study focuses on the time aspect of control. The COCOM was useful for discussing the results from the study as a major theme of control was found.

2.7 Russel's Circumplex Model of Affect

Researchers have noted for some time that people have difficulty judging and describing their own emotional state. This issue suggests that we do not experience emotions as isolated discrete entities but rather that we experience emotions, through an ambiguous interplay of overlapping experiences (Russell, 2009). The two-dimensional circumplex model of affect was developed by James Russell and is illustrated in Figure 1. Russell's circumplex model of affect proposes that all affective states emerge from two foundations: Valence and Arousal. In figure 1 Valence is presented on the horizontal axis from negative to positive and Arousal is presented on the vertical axis from high to low. As seen in Figure 1, the model illustrates emotions assessed by the level of Valence and Arousal. For example feelings of high Arousal and positive Valence conclude in high positive affect and combines to a "Peppy Enthusiastic" emotion. The outer ring presented in the model represents emotions at their extremes and the center of the model represents a neutral state of emotion. This model represents the variation in core emotions and creates a general approach of emotional states (Russell, 1980). The model was used when analyzing, interpreting and visualizing the emotional data from the study that was collected with the Self Assessment Manikin (SAM) method.

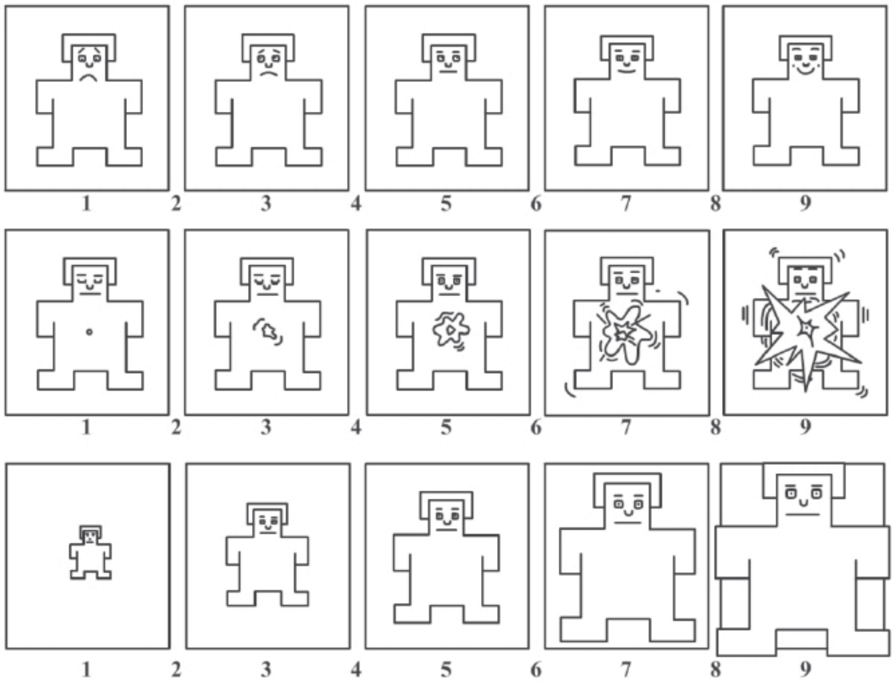
Figure 1: Russell's Circumplex Model of Affect



2.8 Self Assessment Manikin (SAM)

The Self Assessment Manikin was firstly explained by Wundt 1896 as a non-verbal pictorial assessment for which emotional response could be measured by three basic dimensions: Valence, Arousal and Control which is presented in figure 2. These labels were originally labeled: Lust (pleasure), Spannung (tension) and Beruhigung (inhibition). Figure 2 presents the assessment of Valence in the top row with the indication of a frown of the Mannikin for low Valence and a smile for the representation of high Valence. Further Arousal is illustrated in the middle row where low Arousal is depicted to the left and high Arousal to the right. Lastly Control is presented in the bottom row where the smallest Manikin represents the lowest feeling of control and the biggest Manikin illustrates the highest feeling of control. An assessment of 1-9 applies for all the three measurements, where 1 is the lowest possible score and 9 is the highest possible score. Since Valence, Arousal and Control are important factors that may influence the experience of a TOR and the overall take-over scenario, this pictorial assessment was used in the study for collecting the participants' experience of the different parts of the take-over scenario.

Figure 2: Self Assessment Manikin with the measures of Valence, Arousal and Control. First row represents Valence, the second row represents Arousal and the third row represents Control.



3 Earlier research

The previous research regarding transfer of control from automated driving to manual driving has primarily been conducted from a safety perspective, where the pleasantness of the user experience has only received a small share of attention. Earlier research consists mostly of literature reviews, surveys, quantitative analysis and simulator studies. Most studies regarding autonomous driving have been performed using car simulators which often are far from applicable to a real life setting of an AV (De Winter et al, 2021). This aspect is addressed in the discussion section 6.2.2 - Car simulator.

3.1 Non-driving related activities

Several studies regarding autonomous vehicles have investigated NDRAs effect on a take-over scenario, since it becomes a more natural part of the shift in driver behavior. A study by Pfleging et al investigated preferred NDRAs by analyzing which NDRAs that are preferred for passengers to engage in when commuting in public transport and expected NDRAs during highly automated driving (2016). The results from this study showed that the NDRAs that were most preferred as a passenger or during public transport were listening to music, conversing with others in the vehicle, interacting with the in-vehicle information system, eating and drinking, talking on the phone, texting or using social media of some sort. The most preferred expected NDRAs in a CAV, was conversing with others in the vehicle, listening to music/radio etc and watching out the window. The result from Pfleging et al study, inspired the choice of Lego and Video as NDRAs that was chosen for this study. This is further addressed in the method section 4.2.2 - NDRA.

Further findings concerning NDRAs are explored in an extensive survey study by Ataya et al (2021) that explored four different NDRAs (relaxing, eating, watching a video and working on a laptop) with high/low cognitive and physical load assessments. The authors examined preferred interaction from the driver to the vehicle based on the NDRA that the driver was engaging in. Voice input was the most preferred input interaction and showed no significant differences in varying depending on low or high physical and cognitive load. Additional findings from Ataya et al were of inspiration for the assessment of NDRAs, as they assessed NDRAs after cognitive and physical load (2021). The physical load of the NDRA showed the greatest effect on preference of input interaction (Ataya et al, 2021) and in our study we chose video watching and lego building which involved different levels of physical load.

A literature review by Jaussein et al further highlights that NDRAs engaged by the driver affects driver performance and the transfer of control (2021). The research analyzed how engagement in NDRAs was investigated in the context of scenarios of transfer of control from automated driving to manual driving. The authors conclude that reaction time alone would not suffice but rather using deeper assessments about cognitive processes, situational awareness and allocations of mental resources between the NDRA and the driving task. They suggest using a cognitive engagement-centered method when investigating engagement in control transitions in further studies. High and low engagement as well as levels of cognitive load of the two NDRAs: video watching and lego building was assessed with inspiration from findings of Jaussein et al to use a cognitive engagement-centered method when investigating take-over scenarios (2021). To see the assessment of cognitive load used in the study, see method section 4.2.2 - NDRA.

3.2 Timing a safe take-over

Previous research has put a great deal of effort into how to ensure a safe take-over scenario, where SA has proven to be vital to avoid accidents (Stanton et al, 2017). Time has shown to be the number one factor to create SA, which in turn includes that the driver has created an understanding of the current situation and possible future actions (Clark et al, 2019). Further studies that focus on the time aspect is a study conducted by Eriksson and Stanton, who investigated the time it takes for the driver to resume control from a highly automated vehicle in a non-urgent scenario (2017). The study result showed that when participants were instructed to take-over driving while engaging in a NDRA without any time restrictions, it took between 3.17 - 20.99. The authors suggest that this variation should be considered when designing TORs, as the result of the study showed a varied range of time it took to take over driving. The authors further note that there is little use of only taking the mean or median value as it excludes the large portion of drivers.

Further research by Kim et al showed that regardless of modality of the TOR (visual, auditory or both), 10 seconds until take over was the minimum requirement to build situational awareness after the driver has been sleeping (2022). When drivers were given more than 10 seconds until takeover, the study showed that drivers were more aware of their surroundings. Furthermore, drivers also showed a bigger context based understanding of the situation when given more than 10 seconds until takeover, regardless of which modality the TOR was presented with. The authors of this study therefore implies that at least 10 seconds until take over is suitable to safely take over driving and become fully aware of the situation. Visual information was shown to be an effective modality in terms of safety as well as the modality to be the best suited to elicit SA. This is because the driver could quickly process it and therefore have more time to become aware of the situation. Contrarily, the multimodal information of take over results in more effectively perceived information, yet it also demands more time to continuously perceive and therefore it slows down situational awareness. Due to this result, Kim et al suggest in further studies to provide concise and short information with predefined signals or sounds (2022). Considering these results, only necessary and specific information was given as well as a predetermined sound signal for the TOR in the study.

3.3 HMI design for TOR

To create a pleasant user experience of a take-over scenario, the design of the TORs is an essential part to take into consideration. How different combinations of a TOR affected the pleasantness was investigated in a project within Fordonsstrategisk Forskning och Innovation (FFI) Traffic Safety and Automated Vehicles (Rydström et al, 2018). This study investigated how the TOR was experienced by the driver in combination with testing the effectiveness of how to alert the driver of a requested take-over with the focus on human-machine-interface (HMI) design (2018). Results from this study show that the different TOR that were tested were equally effective, although they were experienced differently. The TOR where the sound was divided into two parts was preferred over the TOR where the sounds came all at once. The drivers experienced intrusiveness when multiple modalities were presented at once, which was considered to be unpleasant (Rydström et al, 2018). Considering this, the TOR was designed to be consisting of a sound that was separated from the following take-over voice message.

A study that highlighted the benefits of visual modality is research conducted by Holländer & Pfleging (2018). The authors state that there is an advantage to illustrate the time left until takeover dynamically in a visual manner for the driver, as it enables the driver to perceive the time left until takeover in their peripheral view. This is compared with only showing numbers until take-over, where it's needed to directly point the gaze at the visual TOR to get an indication of how much time there is left (Holländer & Pfleging, 2018). Considering this, the TOR was designed to include a visual element that indicated the time left dynamically until take-over. Further research that highlights the advantages of including a visual modality in a TOR is a study from Kim et al (2022). The study showed trust was perceived to be highest when visual information in the TOR was provided, which indicates that visual information is crucial for trust of the driver. Visual modality was also shown to be the most effective modality to inform the driver according to Kim et al (2022). This was because more information could be transmitted to the driver compared with the auditory modality, thus visual information resulted in a faster way to get situational awareness. Considering support from above mentioned studies (Holländer & Pfleging, 2018., & Kim et al, 2022) it was decided to include a visual modality to the TOR.

Research has also shown that the auditory modality is of great importance to ensure a pleasant user experience when designing the TOR. The design of visual and auditory modalities for a notification was used when informing the driver of situations outside of the vehicle in a study by Najouks et al (2017). The study focuses on how to inform the driver of situations on the road as well as how the interaction is perceived by the driver. Situations outside of the vehicle in this study included lane switching and an upcoming speed limit which the car adapted to. Results showed that participants preferred the auditory information as it resulted in the least distraction from the NDRA the driver was engaging in. Further studies from Holländer & Pfleging (2018) concludes that the TOR should entail both an auditory and visual component. Considering this, it was decided that the TOR should include an auditory modality.

Predictiveness of timing of a TOR has shown to be of great importance when considering participants' preferred design of a TOR, from the result of this study which is further addressed in the result section, 5.5 Themes. Findings from a study by Rydström et al (2018) indicate that a predictability of the automation is important in regards to how much trust the driver felt in the study. The result shows that several participants wanted to “be in the information-loop” to be able to understand the intentions of the autonomous vehicle. Authors of this study concludes that there is a relationship between predictability and trust in autonomous vehicles and that the participants' experience of the AV was constructed as a holistic view dependent on autonomous driving interface as well as driving patterns. Considering this result, the static time frame of TORs was designed to have an intuitive property to elicit familiarity and predictability of the timing periods.

3.4 Attitudes about AVs

Participants' attitudes of AVs were shown to be a prominent factor when analyzing participants' experience of the take-over scenario as well as preferred timing of TORs. This finding is further highlighted in a study by Kim et al which shows that participants' initial opinion on AVs safety is based on previous exposure of AVs, age, income, level of education and monthly petrol cost (2021). The results of this study show significant results in terms of possibilities that the participant may change its attitude towards AVs after exposure with a self-driving vehicle. An additional study that supports the mentioned result is a study by Shi et al, that also concludes that attitudes may change after being exposed to AVs (2021). Gluck et al finds further support for previously mentioned claims when investigating how older people over the age of fifty-five express their attitudes of self-driving vehicles (2021). Overall, skepticism was expressed regarding safety, where trust was a major theme. Yet results from the study indicate that with a little exposure with self-driving vehicles, the participants may be able to familiarize themselves with the AV and feel more safe. Considering findings from these studies, a more practical setup with a driving simulator was used for the study instead of using a survey, in order to follow participants' attitudes of AVs after the test in the car simulator.

Similar findings, as the ones addressed earlier in this section, presented by Haboucha et al (2017) show that attitude is a significant contributing factor whether one can imagine owning AV or not. This study conducted a survey with 721 participants from North America and Israel aimed to investigate if, and why, one would want to own an AV. Results showed that participants possessed large hesitations towards AVs, 44% still wanted to keep their regular cars. Results from the study also reveal cultural differences, where Israelis were generally more positive about switching to an AV. Further indications from the study showed that those who will embrace the trend of self-driving vehicles are people who are young, students, well-educated and people who have spent time in self-driving cars before (Haboucha et al, 2017). Considering this, a homogeneous test group with young cognitive science students was chosen as participants for this study. This target group was argued to most likely be part of the early adopters of AVs and therefore motivates further investigation of their attitudes. How this choice of participants may have affected the result is addressed in the discussion section 6.2.3 Participants.

4 Method

The study was conducted at AI Sweden workplace using AI Sweden's car simulator to use in the test that is presented in section 4.3.1 Car simulator. The take-over scenario is considered to be the whole test procedure, from the moment the AV starts moving until the moment the participant takes over the driving and the test is finished. The participants were divided into two groups, one with a static time frame and one with a dynamic time frame.

4.1 Participants

All participants were recruited through two facebook groups for cognitive science students only at the Applied IT faculty of GU. One person got excluded from the test and there by twelve participants took part in this experimental study, with six participants in each group. The age of the participants ranged from 21 to 29 and there were eight women and four men. All of the participants were students at the University of Gothenburg who had a valid driver license.

4.2 Study design

The design of the study was an experimental setup with the goal to investigate the experience of the test through qualitative measures. The qualitative measures used in this study consisted of SAM measures for three time periods (see appendix 10) of the test:

A: During the beginning of the NDRA, before any take-over request is issued

B: During the first take-over request

C: During the take-over

As well as an additional form that measured the participant´s experience in form of stress levels, mental workload and engagement level, and lastly an interview part. The participants were divided into two groups, where the division of the groups was balanced. One group was assigned a dynamic time frame and the other group was assigned a static time frame. The difference of the static and dynamic group is illustrated in Table 1 below. With the static time frame the TOR was always activated at the same time, regardless of the NDRA. With the dynamic time frame the TOR was activated by different time points depending on the NDRA. Longer time until takeover was given for the more demanding activity in terms of cognitive and engagement level (see Table 1).

Table 1: Timing of the TORs for the Dynamic and the Static test group

Test Group	TOR*	TOR*
Dynamic	Lego building activity: 7 minutes 5 minutes 2 minutes	Video watching activity: 3 minutes 2 minutes 30 seconds
Static	Lego building activity: 4 minutes 2 minutes 1 minute	Video watching activity: 4 minutes 2 minutes 1 minute

*=Informed time left before last opportunity to take-over driving

4.2.1 Take-Over Requests

The audio used for the TOR from the system to the driver were predetermined recordings with timed intervals that were manually played in the beginning of the test. The visual information of the TOR was developed in PowerPoint and ran from that software via a presenter that was manually controlled. Cognitive load of the NDRAs was taken into consideration when presenting both auditory and visual modalities for TOR by the in-vehicle information system, to ensure the message was received regardless of the NDRA the driver was engaged in.

4.2.2 Non-Driving Related Activities

The two NDRA that were chosen for the study were: watching a video and building a lego model (see table 2). The video watching was performed on the participants own mobile device with the use of SVT Play app or web page. The content that was chosen for the participants to watch were three different entertainment programs they could choose in between. The Lego model used for the study was the top part of the Apollo 11 Saturn V lego model (see appendix 3). The Lego material was obtained by AI Sweden. Cognitive load by the participant was taken into consideration when deciding activities, where the lego activity was considered to have high cognitive load and video to have low cognitive load. The amount of cognitive load was assessed as it might have an affect on the participant's experience.

Table 2: Levels of engagement, cognitive load, reward assessment and modality for the two NDRAs in the study

NDRA	Watching a video	Building Lego
Level of Engagement	Low	High
Cognitive Load	Low	High
Reward	None	Yes with external goal
Modality	Visual + Auditory	Visual

The initial level of engagement was assessed by earlier research (Pfleging et al, 2016) and Flow Theory (Csikszentmihalyi, 1975). Findings from Pfleging et al illustrate that many participants would like to engage in different types of mobile activities, such as video watching during an autonomous ride (2016). According to Flow theory, does it need to be a challenging assignment to be able to experience flow and thus be highly engaged in the task. Since video watching was not seen as a challenging assignment, the engagement was estimated to be low. To make the second activity lego challenging and ensure high engagement, was it required that the lego be completed at a specific time. Cognitive load assessment was made with Kahneman's System 1 and System 2. The lego activity was considered to be of high cognitive load since the activity required the participant´s active mental effort to successfully complete the assignment during a short period of time. This included that the participant was required to learn new material, in order to actively start building it together during a short period of time, i.e processed with System 2. On the contrary, the video activity was considered to be of low cognitive load since there was no task that needed to be directly solved by the participant. Besides, the content of the video consisted of entertainment, which was considered to not require any mental effort to create an understanding of. Rather the information processing could be executed passively by the participant and hence, i.e processed with System 1. An external reward was also launched in the form of a trisslott where the participant could win money, to further spark the engagement. Level of engagement and cognitive load was later assessed with likert scales after the activity was performed that confirmed the initial assessment.

4.3 Material and instruments

A car simulator at AI Sweden at Lindholmen was used in the study to create a similar environment to the one of a vehicle. The choice to conduct the study in a car simulator was made to achieve as natural an environment as possible.

4.3.1 Car simulator

The car simulator was equipped with a racing seat, steering wheel and pedals for gas and brakes that had adjustable length. Three monitors were placed in a curved style at eye level of the participant and the sound system consisted of two speakers with surround sound and a bass (see figure 3 & appendix 4). The car simulator was connected to a desktop PC. The dynamic soft-body physics vehicle simulator BeamNG drive was used for this study to support the environment of being similar to a real in-vehicle driving scenario.

Figure 3: The driving simulator setup for the test

4.3.2 Wizard-Of-Oz

The autonomous drive the participant experienced before choosing to take over was conducted with the Wizard-Of-Oz method. The Wizard-Of-Oz method is a technique that is regularly applied with research about AVs. The participant is made to believe that the AV is running on its own, but in reality is there an additional operator that actually controls the driving. Since the software BeamNG where the autonomous drive was held was not able to run by itself, a Wizard-Of-Oz method was applied. The driving/steering was run by one of the test leaders with an additional control device. This control of the vehicle by the test leaders was not made noticeable by the participant and therefore it was perceived as autonomous driving. Two additional PCs (laptops) were used to present the visual and auditory take-over requests, where the Wizard-Of-Oz method also was applied. The take over requests were controlled by the test leaders, but not made noticeable by the participants.

4.4 Procedure

The following paragraphs presents the execution and gives a more detailed description of the design of the experiment. Before the test participant received consent forms and questions via mail to fill out before the test. Upon arrival participants received instructions about the test, and a demonstration in the car simulator was given. Two tests with different NDRAs were performed with an optional break for the participant in between. After the test in the car simulator, rating scales of the experience were handed out and an interview was conducted. The whole procedure lasted around 45-60 minutes.

4.4.1 Pilot study

Pilot studies were conducted early in the study to thoroughly test the choice of NDRA. Furthermore the early pilot testing was conducted with the goal to choose the time interval of the static and dynamic test groups. Five pilot studies were conducted with the same study environment and parameters as in the main study at AI Sweden. These pilottesting was constructed to achieve suitable settings for the study by having the opportunity/time to change possible confoundings.

4.4.2 Pre test assessments

All participants received a consent form and a form with questions via mail to answer before the study (see appendix 5 & 6). Before the test began, the participant had to answer two written questions (see appendix 7), during which time the participant was offered water. Instructions of the test were provided for the participant to read and after any questions, information about the test was given verbally from a script.

4.4.3 Test

Before the test started there was a preliminary phase where the participant became familiarized with the test setup, see section 4.3.1 for further details. The participant got seated in the car simulator and possible adjustment was made with the seating to ensure as comfortable a ride as possible. Use of pedals was addressed as well as what was displayed on the screens in front of the drivers view. The preliminary phase further continued with conducting autonomous drive by Wizard-of-Oz method to create a take-over scenario in order for the participant to get familiarized with taking over manual driving from autonomos drive in the driving simulator. The presentation of the visual and auditory TORs were introduced, where the participant experienced how the visual and auditory signals were displayed during the real TOR. All participants had the chance to familiarize themselves with driving in the simulator until they felt comfortable enough with the process.

The test of the study began in autonomous driving mode at the same time as the participant started performing the given NDRA. The subjects engaged in two non-driving related activities (see table 1& 2) in this study:

- *Building a lego model*
- *Watching a video*

During the Lego activity, the participant was informed to build the Lego model from instructions provided in a paper booklet. The participant would win a "trisslott" if the model had been correctly built and if the participant had taken over the driving before the time had run out. If the test period had run out of time, the vehicle would stop. During the video watching, the participant got to choose from a selection of three different TV shows. The participant watched the video on a mobile phone in horizontal position with sound on. During this activity there was no reward. The order of the NDRAs were balanced to avoid possible confoundings. Jointly with the start of the test, one observer started the predetermined recordings of the auditory TORs. The test leaders applied a Wizard-Of-Oz method during the test. The test observers were seated behind the participant to control the settings of the AV and the display for TORs, without awareness by the participant. After one minute the first TOR was presented, regardless of which group the participant was part of. The TOR informed the driver to prepare to take-over driving and how long there was left until the vehicle would stop. The participant was free to take over the driving anytime from the first TOR, all three notifications would not always have to be applied. The study included two tests, one for each NDRA and after each test the participant answered three SAM measures for three time periods of the test (see appendix 2 & 10). These SAM measures were received after both tests. After the first test the participant got the chance to stand up and take a break before the second test if they wanted to.

4.4.4 Post test assessments

After the two tests two forms, one for each NDRA was given to the participant. Each form contained three likert scales with measures of mental workload, engagement and stress on a likert scale of 1-9 (see appendix 11). During this time the participant was offered "Swedish fika". Interviews were then conducted which were semi-structured. All participants were given all the questions, but the interviewer was allowed to follow up and ask the participant to further develop their reasoning or to clarify if needed. The roles in the interview remained constant, one person interviewed all participants. The interviews lasted around 20 minutes, +/- 10 minutes depending on elaboration from the participant.

5 Results

The illustrated results from the study are presented in section 5.2 in bubble graphs that disclose the SAM results as well as mean value. The bar charts in section 5.4 presents the result from the likert scales and themes found from the interviews are depicted, analyzed and discussed in section 5.5. Research question 1 (RQ1) is considered to be addressed throughout the entire result section. The same reasoning is applied for RQ2 and RQ3, although these sections are mainly addressed in section 5.1 and 5.4 where specific comparisons between the research variables are referred.

5.1 Comparison between static and dynamic time frame and engagement in NDRAs

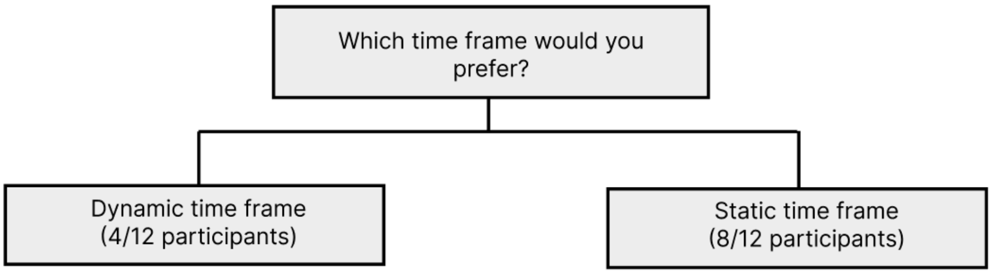
Results from SAM as depicted in figure 5 and 6 did not show any clear pattern of how the experienced time frame affected the participants' experience of the take-over scenario, which addresses our Research Question 3. Neither did the results from the SAM method provide any clear pattern of how participants experienced the performed NDRA which addresses Research Question 2 of the study. Discussion of the usage of SAM as a suitable method is discussed in 6.2.1 -Choice of method. Table 3 below presents observed variations between the mean value of SAM scores (see appendix 20) assessed during the takeover (C, see appendix 10 for further explanation) for the two test groups. The actual mean values are not displayed, since it is the comparison between the static and dynamic test groups that is of value - and not the value in itself. Although small, some differences are visible in the table. Differences of mean values between the two test groups are presented with the label *high* or *low* to illustrate a found noticeable difference. Mean values for Arousal, Valence and Control for both activities and both test groups were compared and differences bigger than 1 was presented in Table 3. Results in the table show that there is a comparable difference in Arousal in both activities between the two test groups. The static test group for example shows a mean score during the takeover in the lego building activity that is higher compared to the mean value obtained by the dynamic test group. There were no addressed differences of the mean values for Control during the take-over in the lego activity.

Table 3: Differences between the two test groups and NDRAs in compared mean values for SAM results during takeover (C)

	Valence	Arousal	Control
Static Lego	Low	Low	__
Dynamic Lego	High	High	__
Static Video	__	Low	High
Dynamic Video	__	High	Low

To further explain the result in figure 4, half of the participants in the dynamic time frame (P3, P9, P11) explicitly said that they felt calm when informed that there were seven minutes left until take-over in the lego activity. Seven minutes were reasoned to be a long amount of time, and all the participants from the dynamic time frame explicitly expressed the benefit of receiving a longer time frame for the TORs during the lego activity. However, it was only one participant in the dynamic group that actually completed the lego assignment. P2 that participated in the static time frame stated that the timing of the TOR was very adequate since the TOR was always issued when half of the time had gone by (4, 2 , 1 min). Four participants in the dynamic time frame (P3, P5, P9, P11) said that it was hard to get a good time estimate of how much time there was left with the dynamic time frame. The dynamic time frame did not obtain the same property of the static time frame mentioned above, where the TOR was presented when half of the time had passed by. Furthermore, the participants said that they would have wanted to know when the next TOR would be presented and it was also these four participants that preferred to have a static TOR. See the preferred timing of TOR among the remaining participants in figure 4 below.

Figure 4: Hypothetically preferred time frame of TORs (see appendix 12 for exact worded question to the participant)



5.2 Assessment of emotional dynamics

The results from the SAM scales are presented in figure 5 below. This figure presents results divided for the two NDRAs in lateral columns where Video watching is illustrated in the left column and Lego building in the right column. Both columns consist of three graphs which represent the three time periods as read in the graph to the left. Each bubble graph in the table presents Valence on the horizontal axis, Arousal on the vertical axis and Control is presented in the size of the data point. The color of the bubble represents the test group where blue illustrates the static test group and orange the dynamic test group. The only evident difference in the data in the graphs below, can be found in participants´ experience during the lego activity during take-over (C) compared with the video activity. Participants´ experience during the video activity was more uniform compared to participants' experiences during the lego activity where it was a more varied and widespread experience.

The mean values of the SAM are presented in the same manner as the SAM scores (figure 5) but in figure 6 below. As can be seen, the mean values for each time frame scores similarly. Here, the biggest difference in perceived experience between the time frames can be found in the video activity during take-over.

Figure 5: Result from both test groups of the SAM during the entire take-over scenario (A,B & C), for the Video watching activity in the left column and of the Lego building activity in the right column.

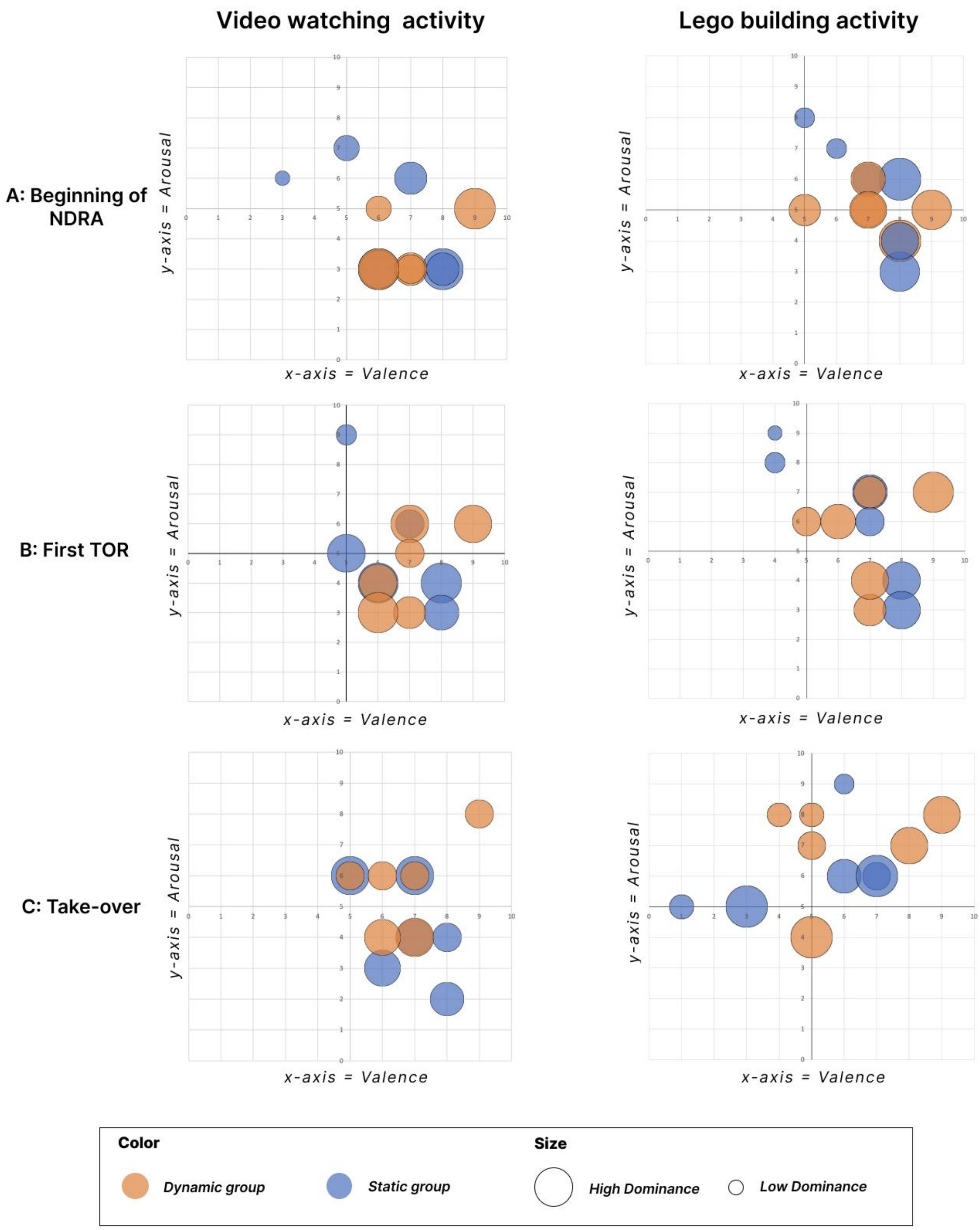
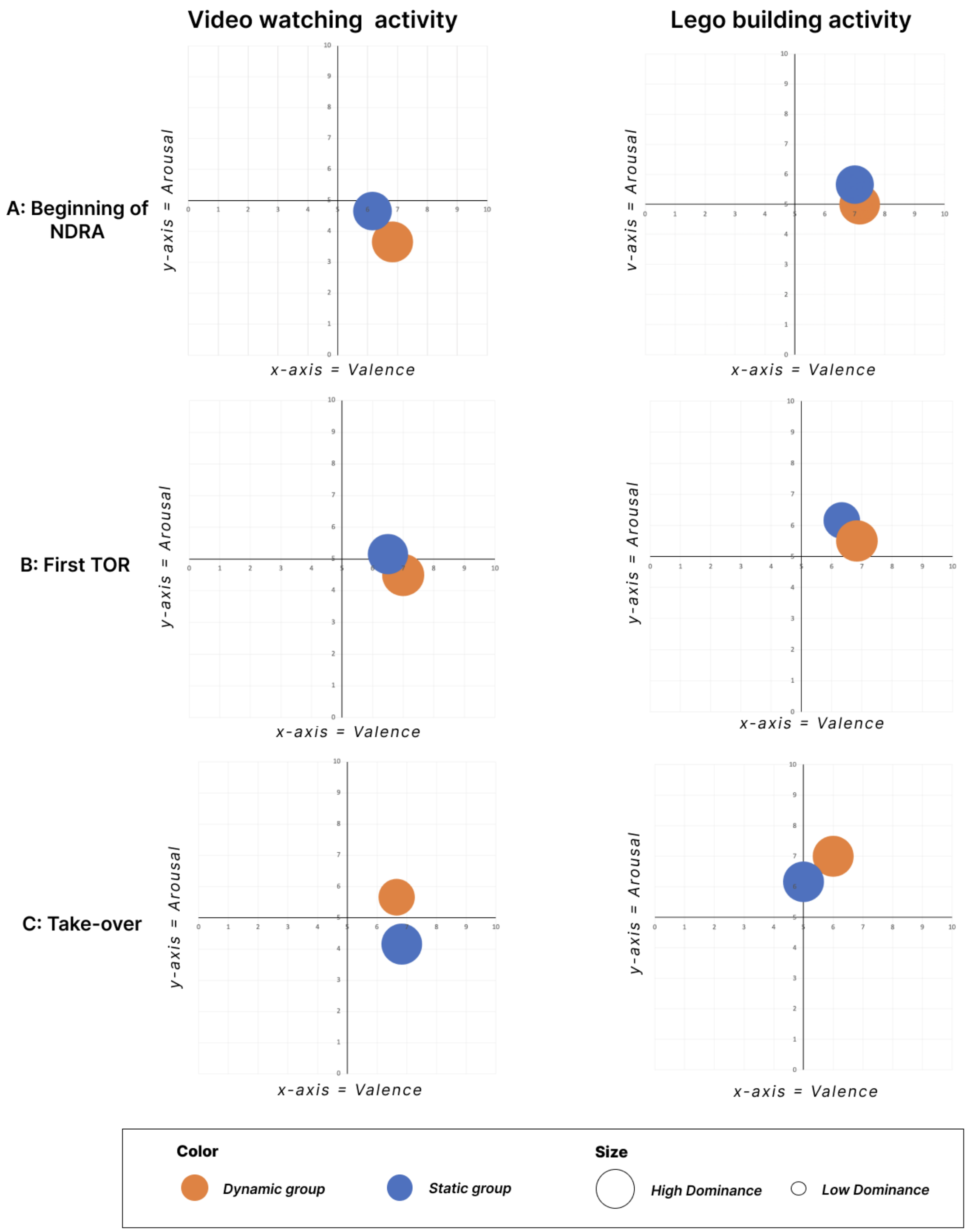


Figure 6: Result from both test groups of mean values for the SAM during the entire take-over scenario (A,B & C), for the Video watching activity in the left column and of the Lego building activity in the right column.



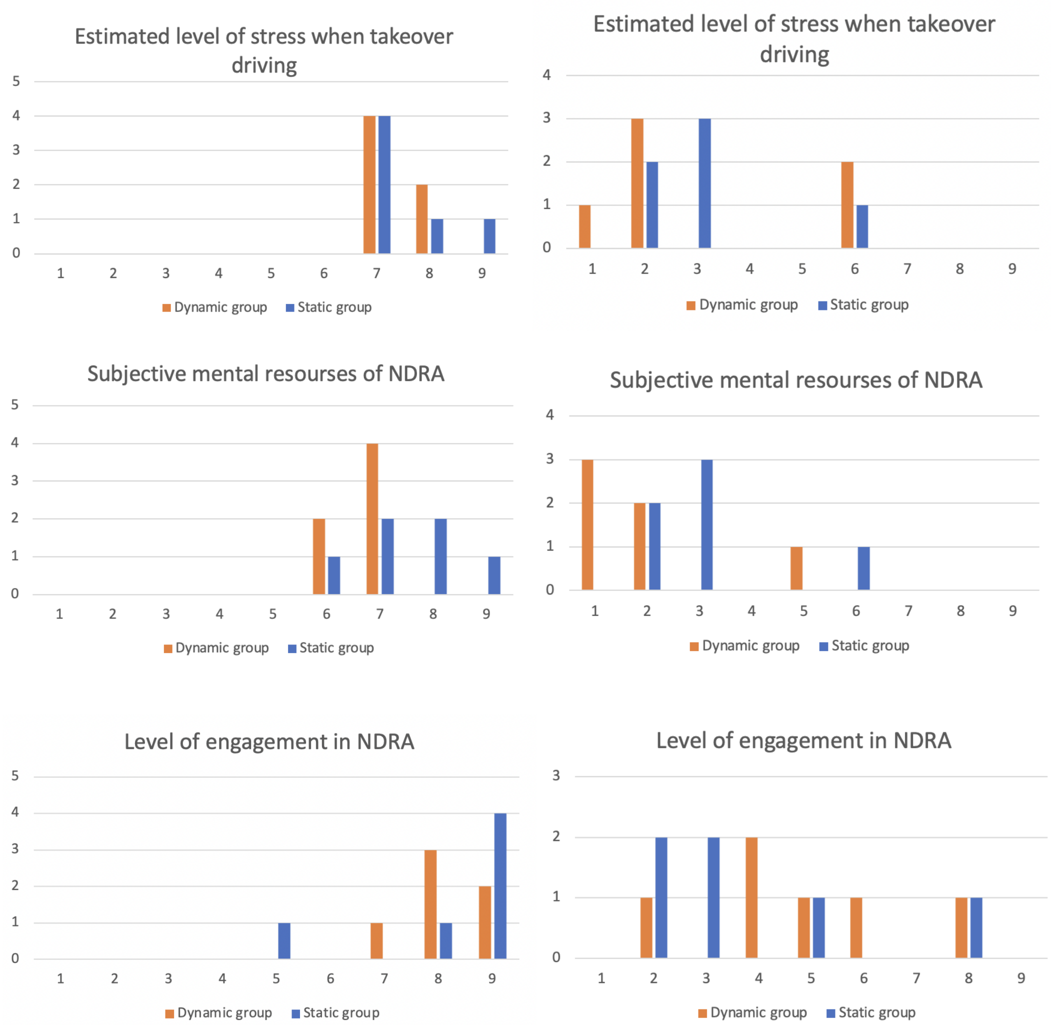
5.3 Individual emotional dynamics

Results in detail of each participant's assessment of SAM is presented in appendix 16 and results of when the participant chose to take over driving is presented in appendix 15. As Stanton and Eriksson points out, there is not much value in only considering the mean values from test groups since it excludes a large majority of the participants' experience (2017). To avoid potentially losing important information that can't be disclosed in the mean, an individual emotional assessment was made where the transition of emotions in each individual was observed. For both activities, participants assessed relatively similar scores of perceived Valence and Arousal during the beginning of the NDRA (A), the first TOR (B) and the take-over (C). However, a larger increase between data points A, B and C on control could be seen for three participants (P4, P8 and P12) during both activities. One participant was in the static and two in the dynamic group. These participants scored a low feeling of control by the beginning of the NDRA, which then increased with the highest feeling of control during the point of take-over. Possible explanations to this are addressed in the discussion section 6.1.5 Individual Differences. On the contrary, the remaining participants reported a lower feeling of control in general during the lego activity compared to the video activity. Furthermore, the remaining participants reported the lowest feeling of control in the lego activity during take-over. One of the participants that reported the highest decrease in control was P6. This participant perceived the static time frame of the TOR and did not take over the driving or finish the lego building model before the time had run out. Possible explanations to this are addressed in the discussion section 6.1.4 Nature of the Non-Driving Related Activity.

5.4 Perceived Mental load, Engagement and Stress levels

Results from Likert as depicted in figure 7 showed clear patterns of how the experienced NDRA affected the participants' experience of the take-over scenario which addresses our Research Question 2. Whereas time frame did not show a clear effect of how the participants experienced the NDRA which addresses research question 3. Results from the three likert scales (1-9) assessed after the study (see appendix 11) are presented in figure 7 below that illustrate participants' estimated levels of stress when taking over driving, subjective mental load and level of engagement of the NDRA. The results for what each participant scored is illustrated in appendix 18, where each single datapoint is reported in a table. All the participants assessed feelings of higher engagement, stress level and mental workload overall, during the lego activity compared to the video activity. This shows that which NDRA the participant is engaged in to a large extent affects how the participant is experiencing the take-over scenario. On the contrary, the experienced time frame of the participant during the test showed no clear effect of how the participant experienced the NDRA. The engagement level of the NDRA also affected when participants choose to take over the driving in half of the trials, where a later take-over could be observed for the lego activity than the video activity.The point of take-over for each participant can be found in appendix 15.

Figure 7: Likert scale questions posterior to the study where answers after the Lego building activity is presented in the left column and answers after the Video watching activity is displayed in the right column. As can be seen, engagement in NDRA showed a clear effect of perceived experience while the time frame did not.



5.5 Themes

The interview data from the study is presented in found themes relevant to our research questions that is presented in appendix 13 & 14. Table 4 illustrates valenced words associated with the experienced time frame in the test.

Table 4: Valenced words associated with the time frame of the two groups

Positive words Dynamic	Negative words Dynamic	Positive words Static	Negative words Static
No interruption in activity	Difficult to adjust	Predictable	Unintelligent
Adjusted for NDRA	Stressful	Safe	Preprogrammed
Personification	Less control	In control	
		Hard to miss	

5.5.1 Attitude

The attitude towards self-driving cars proved to be of great importance when participants reasoned how they would like the TOR to be designed. That attitude has an effect on attitudes towards AVs goes in line with findings from Haboucha et al (2017), see Litterature section 3.4 Attitudes towards AVs. Each participant except P4 explicitly said that they were positive towards AVs. The major fact behind the positive attitude was that it was argued that AVs are safer. A factor that made the majority a bit skeptical of self-driving vehicles was the knowledge that it can be difficult to implement. Ten participants (P1, P2, P3, P4, P5, P8, P9, P10, P11, P12) mentioned that they were aware that there are some obstacles left that need to be solved before fully self-driving vehicles can be implemented. The participants stated that there may be psychological, ethical and practical obstacles. Three participants (P3, P4, P5) addressed the ethical aspect that made them somewhat skeptical about the development of autonomous vehicles. They wanted to know how the car reasoned, to know how the car acts in ethical dilemmas. P5 expressed that "Because eh, if it will make decisions that I do not like, I would probably not want to sit in that car I think. If it were a car that is pre-programmed to drive and hit a child, I don't think that any car would be like that but… Because I have thought about it, it feels like an unrealistic situation but if it needs to choose between me and somebody outside the car, then I don´t know what I want. Because

I do not want to sit in a car that do not prioritize myself, but I would not like to sit in a car that run and hits a child instead of me". Another participant wondered where the legal responsibility would lie in case of an accident. P3 expressed that "Yeah but in case there would happen anything, even if the risk for it to happen something gets smaller, how, where do you put the blame, the legal aspect of it?" Practical obstacles would be how to actually implement AVs in a safe manner. The majority of the participants marked the fact that fully AVs have not reached the market yet, which indicates how difficult it is to implement. One participant (P4) stated that he/she would not drive in an AV until there are only AV on the highway, no ordinary cars.

5.5.2 Engagement

Eleven participants thought that the lego building activity was the most engaging, everyone but P7. To try to complete an assignment under a specific amount of time was deemed highly motivating by everyone but P7, see likert scales figure 7. All participants except P4, P5 and P7 thought that the competition element itself was the most engaging, while P4 and P5 were most motivated by the external reward in the form of a "trisslott". P7 did not feel any motivation of the external reward or by the competition included in the activity as it did not feel achievable for the participant to complete the activity. P7 was thus the only participant who preferred the video over the lego activity. Another observed pattern was that as the higher the engagement level, the less attentive participants were of the surrounding. This was particularly for the lego building activity, where the participants reported higher engagement levels than during video. P4: "I kind of did not even know I was in a tunnel until I got a warning that there were 4 minutes left". P12 mentioned that he/she was almost close to missing the message. In connection with this, five participants (P2, P7, P10, P11, P12) mentioned that it would have been desirable to have an extra modality like tactile, to message the driver to make sure that they would not miss it. In addition, there were no problems during the video activity to comprehend the HMI, except for P7 that had high volume on their phone during the video activity.

5.5.3 Perceived Intelligence

Overall, all participants stated that an intelligent car should be able to act in all different situations, even unpredicted ones. In other words, it should always be able to adjust accordingly. It should also be able to analyze its surroundings, and make decisions that are safe. Eight participants (P2, P5, P6, P8, P9, P10, P11, P12) stated that the interaction, i.e. messages, felt unintelligent. Four participants (P2, P6, P9, P12) said that it felt unintelligent because the interaction felt pre-programmed. However, two participants (P5, P11) reasoned whether it was necessary for the situation that the interaction actually was intelligent. Furthermore, two participants (P11 P2) raised doubts whether a car ever can be sufficiently intelligent to classify your actions and message you accordingly in order to have an activity based communication.

5.5.4 Control

A major recurring theme that has been observed in the study is the desire to receive more information of what will happen next in order to feel more control over the take-over situation. Possible explanations to this arising theme is addressed in the Discussion section 6.1.1 Timing.

Half of all participants stated that they wanted to know how the car reasons and behaves overall. It was not considered necessary at every decision the car made, but more an understanding of how the car will act and why. It would have made the participant feel calmer, and a greater sense of control. That participants took over earlier in the video activity compared to the lego building activity was mostly explained by the engagement level. Participants argued that if they were not engaged in the activity, then they found no reason for not taking over the driving again, rather they would then just worry that they might miss the actual take-over. P8: “Yes but on the first test (video) I did it because... yes, but it felt like when time started ticking down so okay I know I will get more messages but it felt a bit like the more time goes by that you might lose control a little gradually because you were not really sure how much time you had left… () I do not know if I can develop more. But it is the case that you get a little automatic stress when you know that it is a time that ticks down. And then I probably felt that I could just as well do it now (take over the driving) instead of waiting”. Another factor that was of interest was that when the participant chose to take over was that at least partly, it was affected by what the environment looked like. Five participants (P11, P9, P5, P6, P7) said that they wanted to take over when it was deemed to be "easy". Examples of such easy situations to take over were when the car was at a red light and at a straight line. Seven participants stated that they would not engage in an activity that took up all their attention such as lego. They would like to feel that they have a little more control over the situation, but the lego activity did not allow them to do so, which made them stressed. Four participants (P3, P5, P7, P11) stated that they had not felt comfortable now to ride in an autonomous car and completely let go of control. But all of them also opened up to the possibility that they could become more comfortable in the future. Two participants stated that they felt more comfortable already from the first to the second round of the test. Furthermore, all of the participants that wanted the static time frame said things that indicated that they feel that it is their responsibility to ensure a safe TOR. One participant mentioned that it would not feel comfortable with the car filming to be able to classify correctly to have an activity based interaction.

5.5.5 Time

Eight out of twelve participants stated that they would prefer to have static communication where the TOR is always issued at the same points in time. Possible explanations to this are addressed in the discussion section 6.1.2 Known expectations. The exact wording of the question can be found in appendix 12. Out of these eight participants, four participated in the dynamic group and four participated in the static group. There were several reasons why the participants preferred a static time frame. The crucial one was that it felt safer. With the same time frame each time, the participants argued that you can learn the pattern, and adapt accordingly. It was also argued that it was less risky to miss the actual take-over, since the participant has the possibility to learn when the messages are coming. On the contrary, all the participants from the dynamic time frame explicitly said that they considered it to be a benefit that they received a longer time frame to the lego activity. However, it was said to be stressful not knowing then the TOR would be presented. As a response to this, two participants suggested that it may have felt less stressful if there was a display that informed when the next message would come. Nonetheless, four participants stated that they preferred to have dynamic communication where the message would be adapted based on present activity. Two had participated in the static time frame and two had participated in the dynamic time frame. It was argued that it would be nice to have the possibility to have personalized and adapted communication, and hence, avoid being interrupted in activities. However, during further conversations the participants opened up to some more nuanced answers. These include alterations of the communication, where participants reasoned that it would be good to have a set baseline but with the possibility to personalize the TOR to make it fit you even better.

5.5.6 Opinions about other elements of the study

The majority of participants thought the set up felt natural, or quote “as natural as it can be with a simulator”. Several stated various things that made it not feel like a real car, like a missing speedlimitor, but participants said that the set up was sufficient to be able to imagine a real-life situation. All participants stated that they liked the auditory HMI. However, P7 said the auditive message would need to be louder. P7 had high volume on the phone while watching the video activity, which might have contributed to the answer. However, both P4 and P10 said that it might have been easy to miss the message if there were a lot of surrounding sounds, quote “like if you listen to music with high volume and speaking with your friends”.

There were different degrees of dissatisfaction with the visual HMI, all participants but one were less satisfied and wanted to adapt some changes to it. The major theme of the dissatisfaction was that they did not get a clear visual idea of how much time there was left. This goes in line with earlier research from Holländer & Pfleging (2018), see chapter 3.3 HMI design for TOR. Furthermore, how this might have affected our result is addressed in the Discussion section 6.2.5 Design of the TOR.

6 Discussion

This section includes a discussion about the result from the two tests, results from the static and the dynamic group as well as found themes in attitudes of AV and experiences of the test. The method and possible confoundings are also discussed.

6.1 Factors that influenced the experience

A major recurring theme that has been observed in the study is the desire to have control over the take-over situation. Eight out of twelve participants preferred a static TOR, where participants reasoned they would feel more in control when they knew when a TOR would be presented.

6.1.1 Timing

According to the COCOM theory, a large part of control is how to plan your time and your actions within the specified time horizon. With the dynamic version, one can argue that it did not allow participants to plan their time. Many participants stated they were less aware of the time frame since they did not know when the next TOR would arrive. Furthermore, COCOM theory states the importance of having sufficient time to be able to plan future actions. Participants in the dynamic time frame received longer time than participants in the static time frame to be able to complete the lego activity and without getting stressed. With that type of reasoning, the dynamic time frame should also make the participant feel more in control because the participants are given a longer time to prepare for take-over if needed. However, it was only one participant from the dynamic time frame that actually completed the lego. This might imply that the dynamic time frame was too short. The results state that all participants in general felt stressed during the lego activity, regardless of time frame. The stress levels would probably have decreased in the dynamic group if the participants received an even more extensive time frame compared to the static. This in turn might have made the participants favor the dynamic TOR a bit more during that specific lego task. This was not observed for the video.

6.1.2 Known expectations

Another way to increase control according to the COCOM model is to reduce the time to select actions. Several participants argued that they would prefer the static time frame because then they would learn the procedure and prepare accordingly.

One could argue that with these known expectations as exist in the static time frame, you reduce the time so select actions and ie, increase the feeling of control. Eight out of twelve participants preferred a static TOR when asked to imagine a hypothetical scenario, where participants reasoned they would feel more in control when they knew when a TOR was issued. Studies from Rydström et al (2018) shows that predictability of how the car will behave will infer more trust with the driver. This may explain the preference for the static TOR, since static TOR has a predicted outcome.

6.1.3 Feelings of responsibility

People who preferred the static time frame motivated their choice by feelings of higher control of the situation that was obtained if the TOR always was presented at the same, predetermined time, since the static time frame therefore felt safer. This indicates that the participant did not place sufficient trust into the system to ensure a safe take-over, which also might indicate that the participant feels responsible for a safe take over. That participants place that responsibility on themselves might be due to individual differences since some of the participants that preferred the static version explicitly stated that they are careful as persons. This is further discussed in section 6.1.5 Individual differences.

6.1.4 Nature of the Non-Driving Related Activity

Participants scored in general a lower feeling of control overall in the legotest, but even more so as the test proceeded. This might be due to the uncertainty of whether the participant would be able to complete the activity before the time was due and take over the driving. This implies that the nature of the NDRA and the time frame can be seen as an important factor for the feeling of control, since many participants stated that they were highly motivated to finish the lego activity.

6.1.5 Individual differences

Attitudes proved to be one of the key factors to how the participant experienced a take-over scenario. Since fully autonomous vehicles have not yet entered the market, participants lack the possibility to assess AVs based on their experience. Therefore it's not surprising that the results show that the attitude participants possess of AVs influence their experience of a take-over scenario in a driving simulator. Further results may imply that differences in personality influenced the experience. This could be observed by how participants reported feelings of control. The majority of the participants reported the lowest point of control during take-over. On the contrary, three participants reported the exact opposite, with the highest value during take-over. The same pattern could be found during the video activity for these three participants. This implies that the nature of the task did not matter as much for the feeling of control for these three participants as it did for the rest of the participants. Rather, there seem to be other personal differences that determine the feeling of control.

6.2 Observation about the method

The study was initially meant to be performed with the help of Smart Eyes in-vehicle monitoring cameras together with a virtual prototype that controlled the auditory TORs, which was developed by RISE. Due to changes that appeared in the RE-ENGAGE project the study had to be redesigned to use the Wizard-Of-Oz method for this purpose. It is technically feasible to transform our method to an autonomous process in further studies. The monitoring of NDRA was resolved by having predetermined activities and predetermined visual and auditory take-over requests for both the dynamic and the static test groups. This would as well be technically feasible to transform to an autonomous process.

6.2.1 Choice of method

The use of a qualitative method was determined by RISE to obtain nuanced and elaborative data that provided more valuable information of the experience. The interviews conducted with the participants showed that NDRAs and attitudes were the main influences that affected the participant´s experience of the take-over scenario. Since attitudes of the participants were not considered to be visible in the results of the quantifiable likert scales and SAM, the qualitative method is considered justified. Besides, as Eriksson and Stanton (2017) points out, there is little use of only taking the mean or median value as it excludes the large portion of drivers. That is, a mean does not embrace the full depth of individual differences. Therefore, a quantitative study was not considered to be able to answer our research questions nor satisfy our purpose with the study. In addition, it was considered difficult to link interview responses to specific data points because the quantifiable scales did not clearly address what was addressed in the interviews. Therefore, no comparison was made between specific data points and the respective interview answers. Another result that could be observed was that the SAM results did not show any clear difference in experience in terms of experienced NDRA - while results from the likert scales did as well as the themes. This can be interpreted as SAM not being the best suited method for the research questions assessed in this case.

6.2.2 Car simulator

The study was conducted using a car simulator (see appendix 4). Overall, the participants experienced the interaction of the TOR from the system to the driver positively and deemed it sufficient to function in a real AV. But as De winter et al (2021) raised critics towards, results from driving simulator studies may have no external validity since a simulator study is far from a real life setting of an AV. There is no real traffic and you therefore have zero possibility to actually be injured during a ride. This factor may account for the possibility that participants feel more comfortable and relaxed in a driving simulator than they would actually feel or behave in a real AV. Some participants explicitly said that they did not think they would behave in a real AV as they did in the study, which included what activities they likely would engage in and how relaxed they would be in an AV. This can argue for a lower external validity.

6.2.3 Participants

The number of participants who partook in this study was limited due to changes in the project and time restrictions of the thesis. 12 participants were chosen for the test to be able to have six participants in each group which was considered to be sufficient for the purpose of the study.

All our participants were students in the age of 20-29. Results from Haboucha et al, 2017 have shown that higher education level is one factor that contributes to a more positive attitude towards AVs. Our participants were all cognitive science students, where artificial intelligence is a present course in the program. This means that they presumably have more knowledge about AVs than the average person. This factor might have contributed to the general positive attitude towards AVs. Several articles (Kim et al, 2021., Gluck et al, 2021., & Haboucha et al, 2017) show that with education and exposure about AVs can make the participants more positive towards AVs. All participants but one reported that they had not been riding or driving in an AV or in a driving simulator before. However, several participants mentioned that they might change their attitude once they become more familiarized with the vehicle, and one participant mentioned that they felt more comfortable already in the second round and hence, found the ride more pleasant. That is, if participants would have repeated this measure several times, they might have become more comfortable, which may cause a more positive attitude. Furthermore, the order of the activities were balanced with changed order for different participants to account for the fact that the participant might be more comfortable in the driving simulator the second time.

6.2.4 Duration of the study

The test was designed to not take too long as it was discussed to affect the result from the study negatively if the participant got tired or bored. This was also the reason why there were two test groups instead of letting the participant engage in the same NDRAs two times to test both the static and the dynamic time frames. Providing the participant with information about the study during multiple occasions (before the study via mail, written explanation before the test and vocally before the test) was done to minimize overload of information processing and risk tiering/exhaust the participant.

6.2.5 Design of the TOR

All the participants reported that they in general were satisfied with the TORs in terms of visual and auditory information. A recurring note from the participants however was that the dynamic bar displaying time left until takeover was ambiguous and unclear and this can therefore have contributed to unnecessary confusion around time left to take over. This might have contributed to earlier takeovers than if the bar was more precise. A more precise visual presentation of time left may have resulted in less anxiety, and later take-overs if drivers had a more precise time perception . A more precise visual presentation of time may lead to less concern of how much time there is left. However, if the driver takes over driving later due to a more precise visual representation, one could argue that it may become more stressful as time until take-over would become more critical.

6.2.6 Wizard of Oz method

The autonomous drive that was done by the observer of the study did not show an effect of dependence. As the test continued the driving was done with greater ease and comfort in terms of a more stable drive. This was not something that was noted by the participant as the steepest learning curve occurred during the pilot testing.

6.3 External Validity

Due to time limitations the study only included twelve participants. However, since the study had a focus on analyzing results in depth from the participants that partook in the study, generalizability of the data was never the goal. Instead participants received the possibility to develop their attitudes and experience of the take over scenario as semi-structured interviews were used.

6.4 Ethics

Participants were informed about the study in a short description before volunteering to participate in the study. Form of consent and related questions were sent out before the study where the participant had to confirm being part of the study and giving consent for being recorded during the interview. Since the study was voluntary, the participant was informed that the participant could cancel the study if needed.

7 Conclusion

This study gives an important contribution to the important discussion of how a pleasant TOR should be designed. Findings from this study highlights the importance of taking the nature of the NDRA into consideration, as it to a large extent affects the experience of the take-over scenario. The purpose of this study was to examine the user experience in relation to engagement in NDRA and the timing of the take-over request in autonomous vehicles. This was done by examining participants' experience of the take-over scenario and how participants experience the communication between the driver and the system, as well as the NDRA. Two NDRAs were selected to see if and how different conditions may affect one's experience, where the NDRA was divided into two engagement levels, high and low. Likewise the timing of when the take-over requests (TOR) were issued was divided into two different groups, dynamic and static. Dynamic entailed that the TOR was adjusted according to the NDRA the participant was engaged in, while static meant that the TOR always came at fixed points in time. Theories used for designing the method of the study were Cognitive Load theory, and Flow theory. Whereas theories used for analyzing and interpreting the result were Russell's Circumplex Model of Affect, Sam Mannequin scale, Situational awareness, Contextual Control Model and Grounded theory.

The research questions for the study are considered to be addressed, and can be found in section 1.4- Research Questions. Research question 1 (RQ1) is considered to be addressed all throughout the result section, see section 5. The experience of the take-over scenario is measured in several different formats, where every measurement contributes to describing a rich picture of the participant´s experience of the take-over scenario. Results show that which NDRA the participant engaged in, was the main contributing factor for how the participant experienced the take-over scenario. RQ2 addresses if any patterns can be observed in perceived experience of NDRA. The results show that NDRA affected stress levels, engagement levels, mental workload, and reported emotions (valence, arousal & control) assessed through SAM scale. RQ3 addresses if any patterns can be observed in perceived experience of time frame. Results show that the time frame in which the participant participated did not show a clear effect on the experience of the take-over scenario in terms of measurements used in this test. The time frame did not affect stress levels, engagement levels, mental workload, and reported emotions (valence, arousal & control) assessed through SAM scale.

Further results show that experienced timing of the TOR in the study did not affect which timing of the TOR the participant would prefer for hypothetical scenarios. Instead, attitude towards AVs proved to be the main influence of how participants reasoned about preferred design of the TOR.

Additional results show that participants show a general preference for the static time frame for TORs as it enables them as drivers to feel more in control. A static time frame was said to contribute to a more suitable understanding of expected behavior from the AV. This predictive property of the static time frame was argued to be a key factor to the shown preference. Further factors that proved to be of importance was also perceived intelligence of AVs and individual factors of the participant. It is not possible to make any generalizations due to the small sample in this study, therefore it would be interesting to further investigate the experience of the TORs in greater scale and further detail. It would also be of interest to test how the familiarization with the AV may have an affect on attitude and preferred interaction between driver-vehicle. *Furthermore, it would be interesting to investigate how the attitudes may vary depending on gender, age and social position.*

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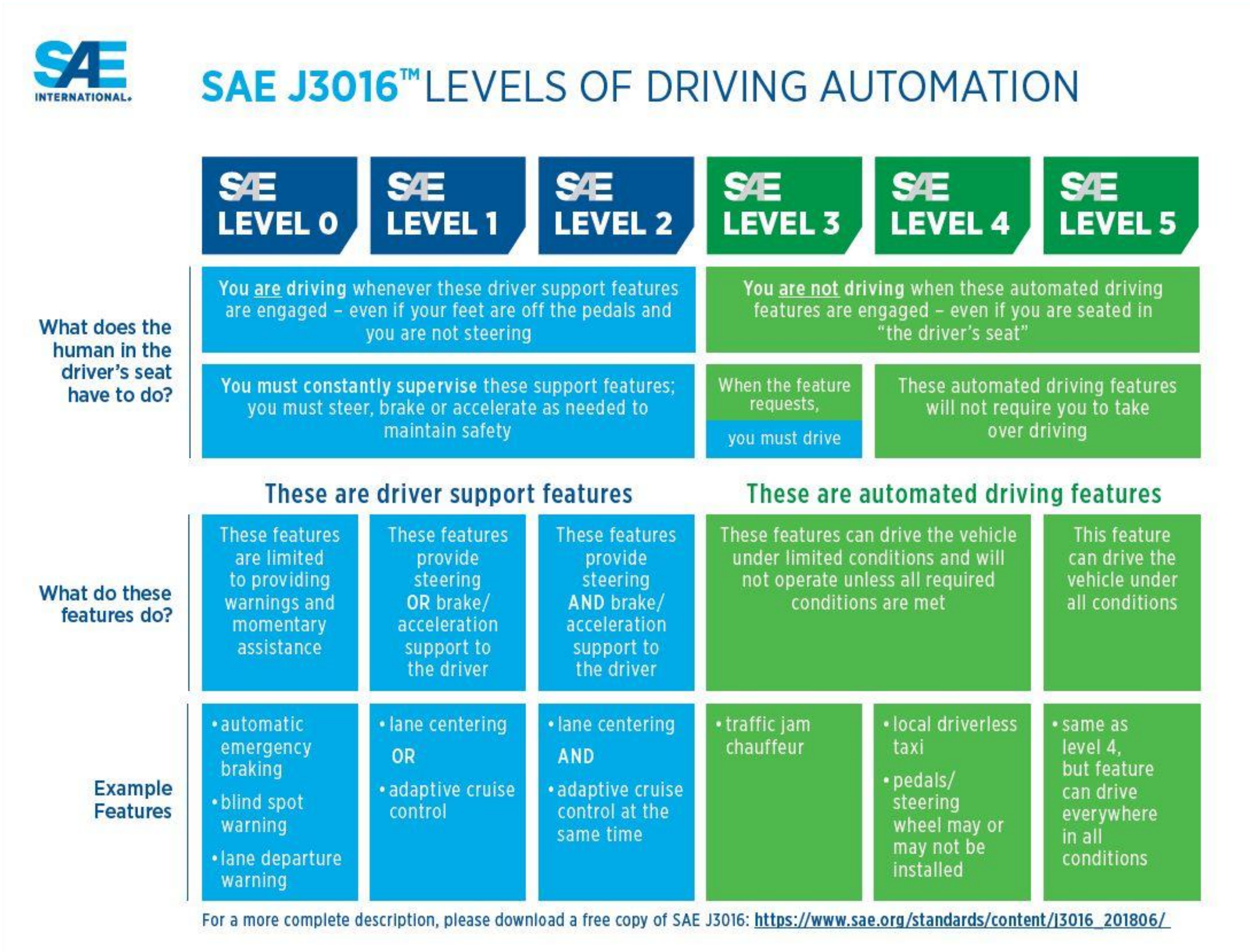
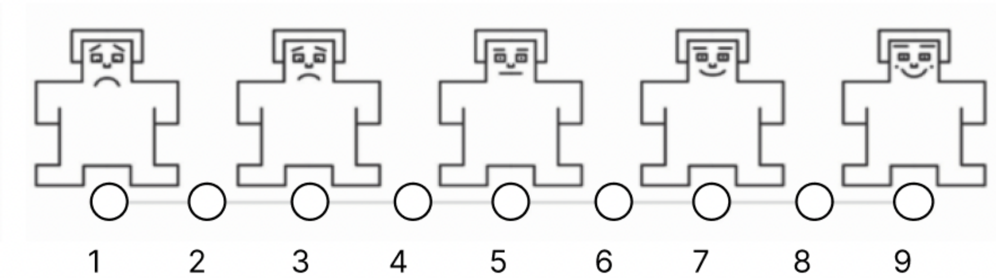
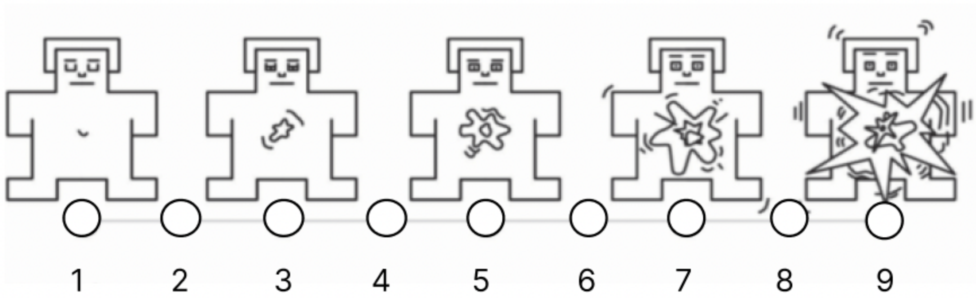
9 Appendices

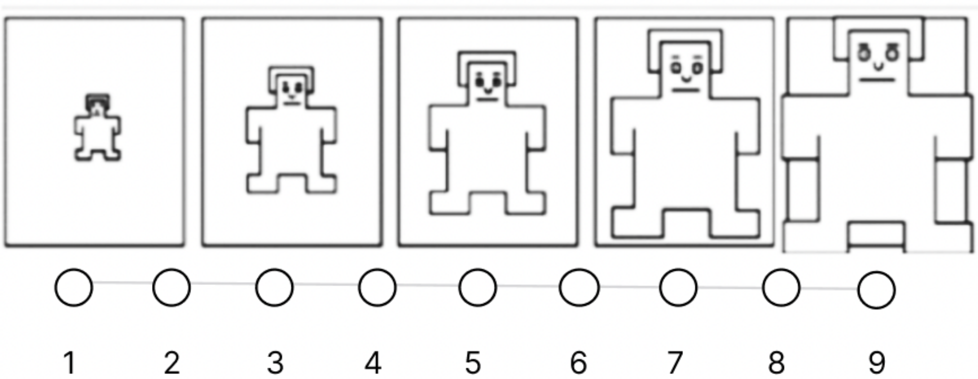
Appendix 1: SAE Levels of Driving Automation



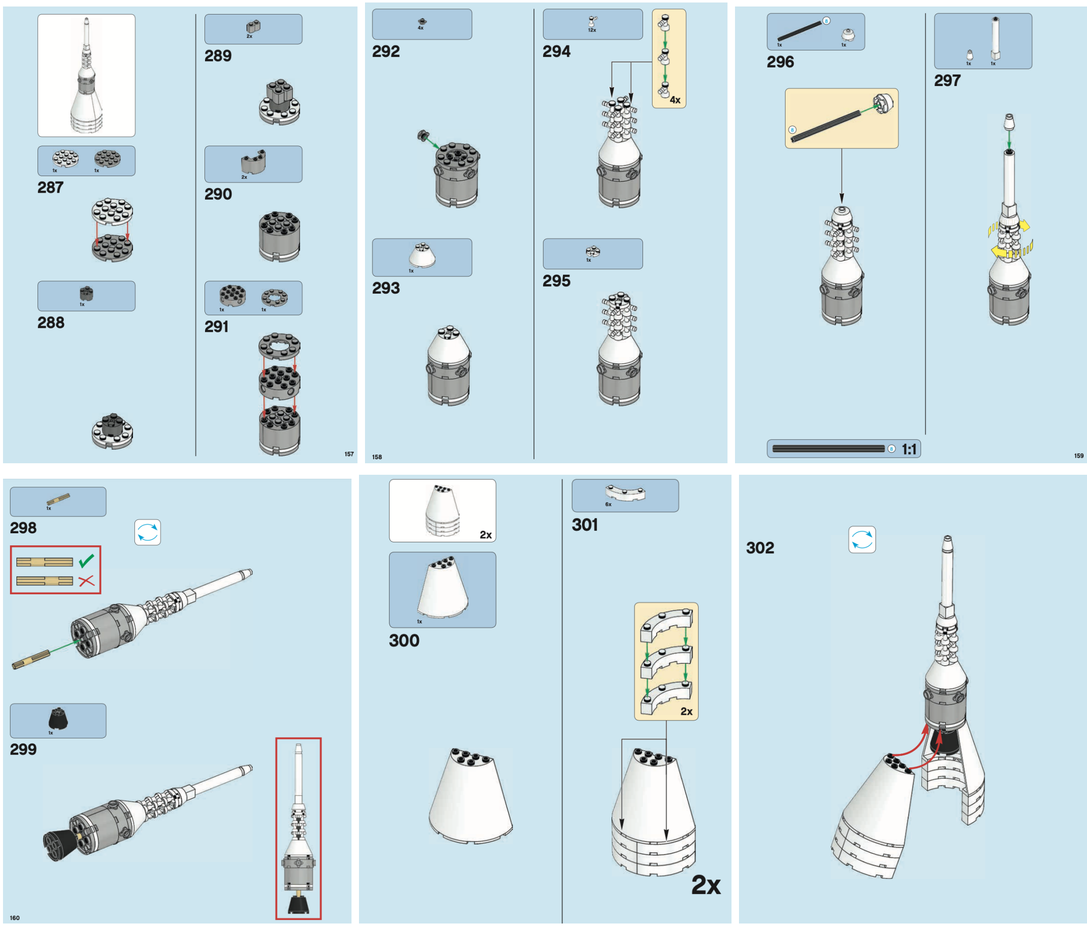
Appendix 2: SAM (1-9)







Appendix 3: A/One/The top part of the Lego model NASA Apollo Saturn V



Appendix 4: Car simulator setup

Appendix 5: Consent form

This form contains points you need to approve to participate in our study. All points need to be approved (tick the boxes). By participating in our study, you agree to the following points under "I hereby agree to:".

I hereby agree that:

- ☐ My voice is recorded during the interview
- ☐ All information regarding the test design, measuring equipment and results is strictly confidential. You are therefore not allowed to disclose any of this to any other person such as a colleague, family member or friend until the study has been completed.
- ☐ Your answers and your results will be processed so that unauthorized persons can not take part in them.
- ☐ Data and conclusions from the study may be published, but your identity will never be revealed.
- ☐ I know that no answers from the study will be disseminated or can be linked back to me personally, everything will be presented anonymously.
- ☐ I give my consent to the University of Gothenburg and RISE (Research Institute of Sweden) to store and process the information collected during the study.
- ☐ I am well aware that I participate in this study completely voluntarily and I know what the overall purpose of the participation is.
- ☐ I'm aware that I can cancel my participation at any time and I do not have to explain why that would be the case.

DATE: Gothenburg on…. /…. 2022

Signature

…………………………………… .. ……………………………………

Appendix 6: Question form

Question*
"What do you identify as?"
"What is your age?"
"Do you have any visual or auditory impairments?"
"Have you been driving in a driving simulator before?"
"Have you played computer games that include car driving before, such as GTA, Forza Horizon and Dirt Rally?"
"How long have you had a driver license for?"
"How often do you drive a car?"

**For result see appendix 8*

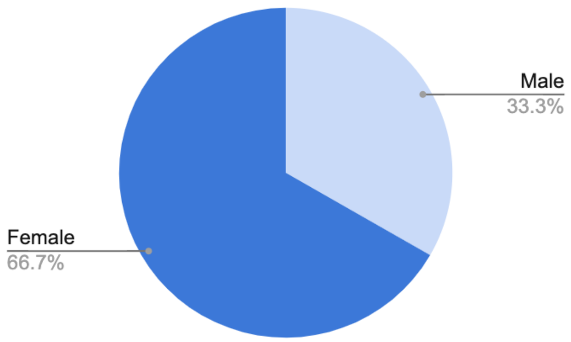
Appendix 7: Pre test questions

Question*
"How are you feeling today on a scale from 1-9?"
"Do you usually build Lego?/Do you build with Lego on a regular basis?"

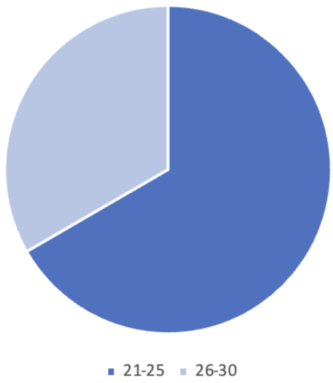
**For result see appendix 9*

Appendix 8: Result from the question form presented in pie charts

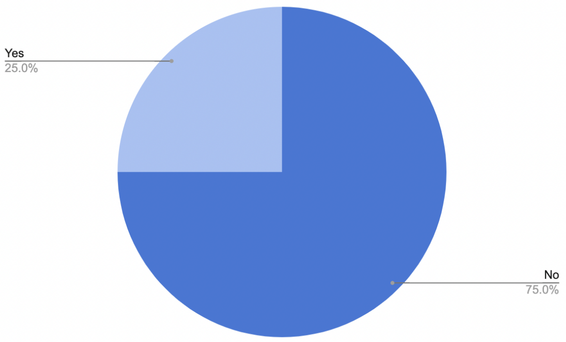
Gender:



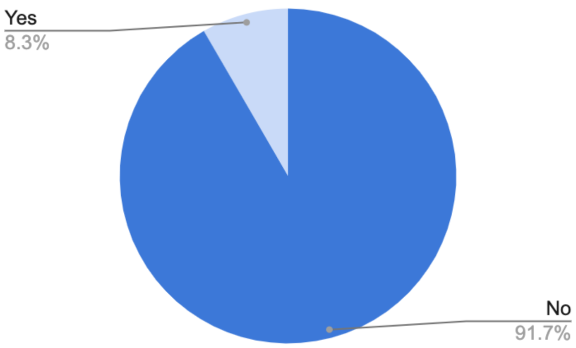
Age:



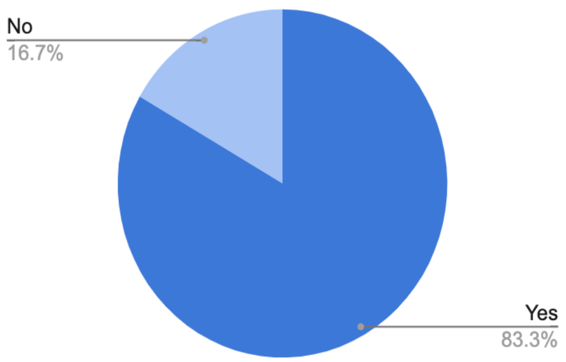
Visual/Auditory impairment:



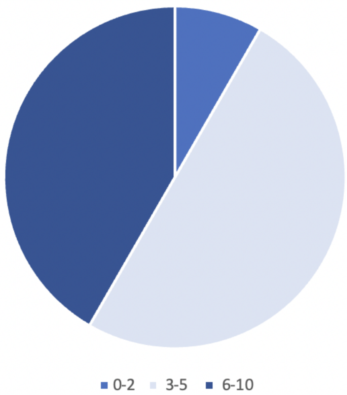
Driven in a driving simulator before?:



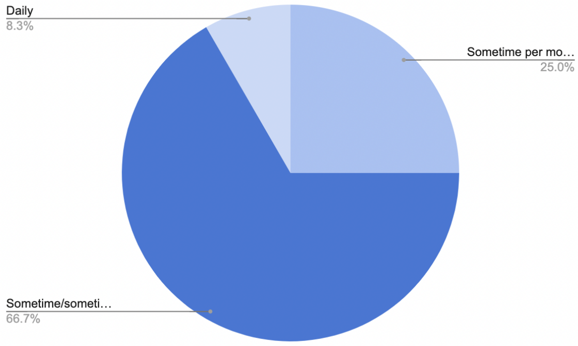
Played computer game with car driving:



Years of obtained driver license:

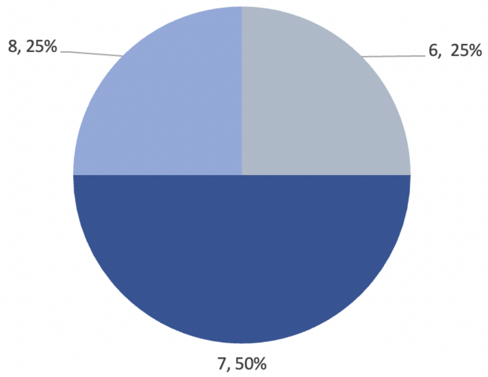


Driving habits:

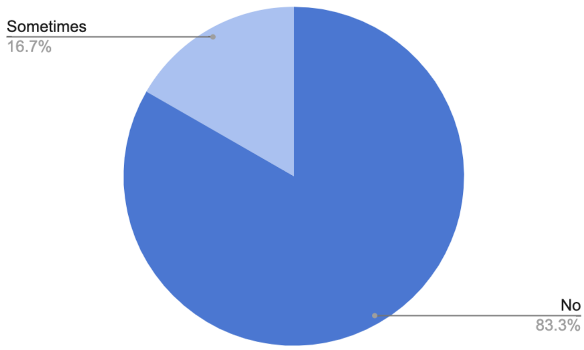


Appendix 9: Result of the questions preliminar to the study

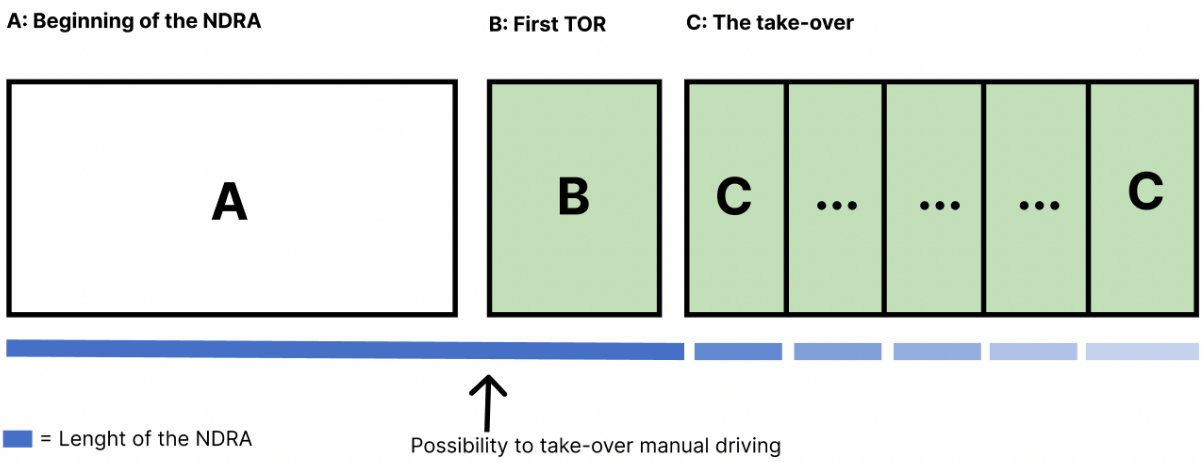
How are you feeling today on a scale from 1-9?:



Do you usually build Lego?:



Appendix 10: Illustration of the three time periods (A, B and C) for SAM scale measures



Appendix 11: Post test likert scales (1-9) for both activities - lego building and video watching/Questions on a scale of 1-9 after the participant has completed the activities

1. How stressed did you feel on a scale of 1-9 at finishing the activity you were doing when you were about to take over driving? 1 means you were very calm and 9 means you were very stressed.

   Answer:

   ○ ○ ○ ○ ○ ○ ○ ○ ○

   1 2 3 4 5 6 7 8 9

2. Can you estimate on a scale of 1-9, how much mental resources the activity required? 1 means that you did not have to make an effort at all, but the task could be performed on pure automation, and 9 means that you just managed to perform the activity but you experienced it as very difficult.

   Answer:

   ○ ○ ○ ○ ○ ○ ○ ○ ○

   1 2 3 4 5 6 7 8 9

3. How involved did you feel in the activity on a scale of 1-9? 1 is that you were extremely bored and where you spent most of the time thinking about other than the task, and 9 means that you were fully engaged and had your full attention only on the task.

   Answer:

   ○ ○ ○ ○ ○ ○ ○ ○ ○

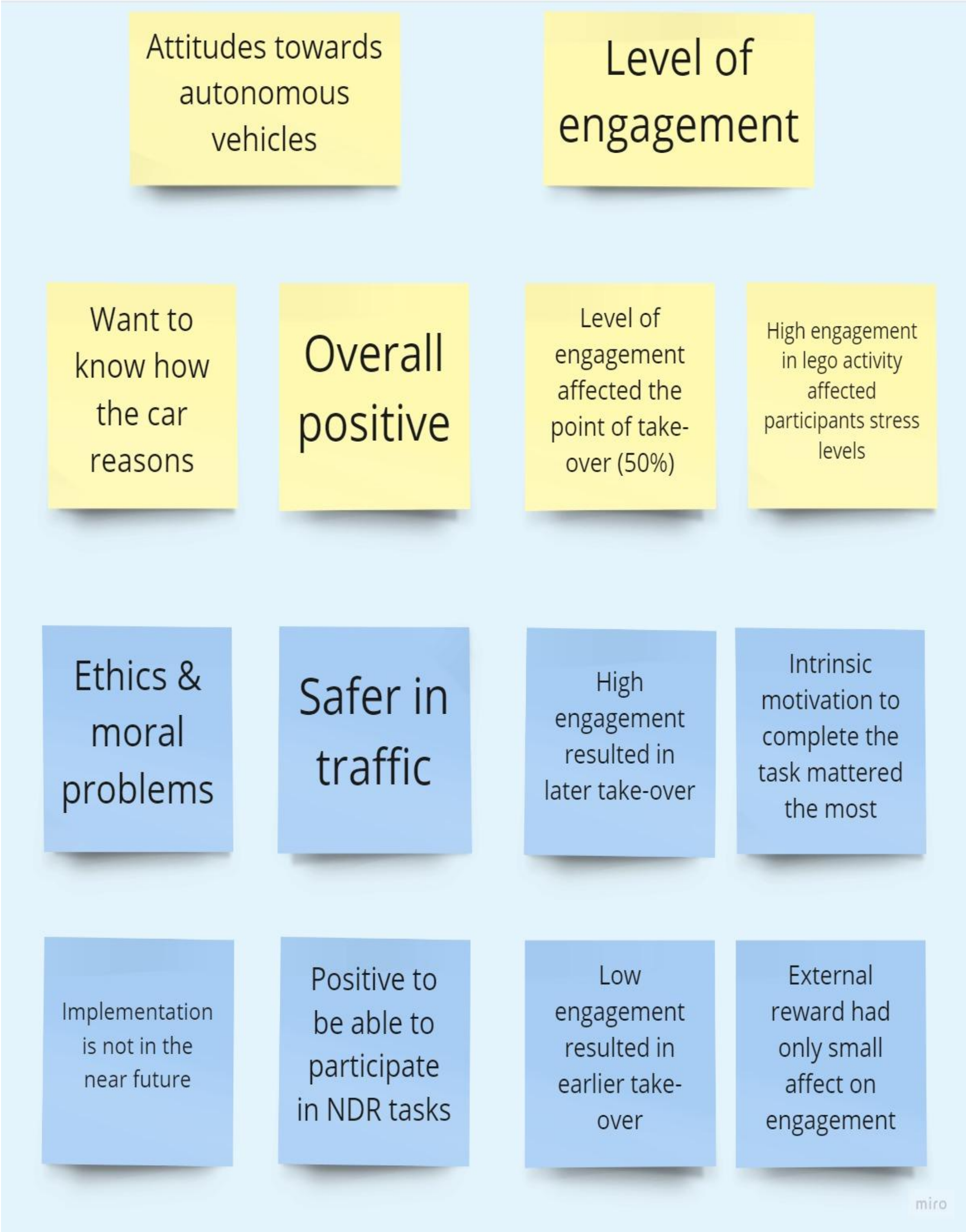
   1 2 3 4 5 6 7 8 9

Appendix 12: Worded question from the interview about static or dynamic HMI

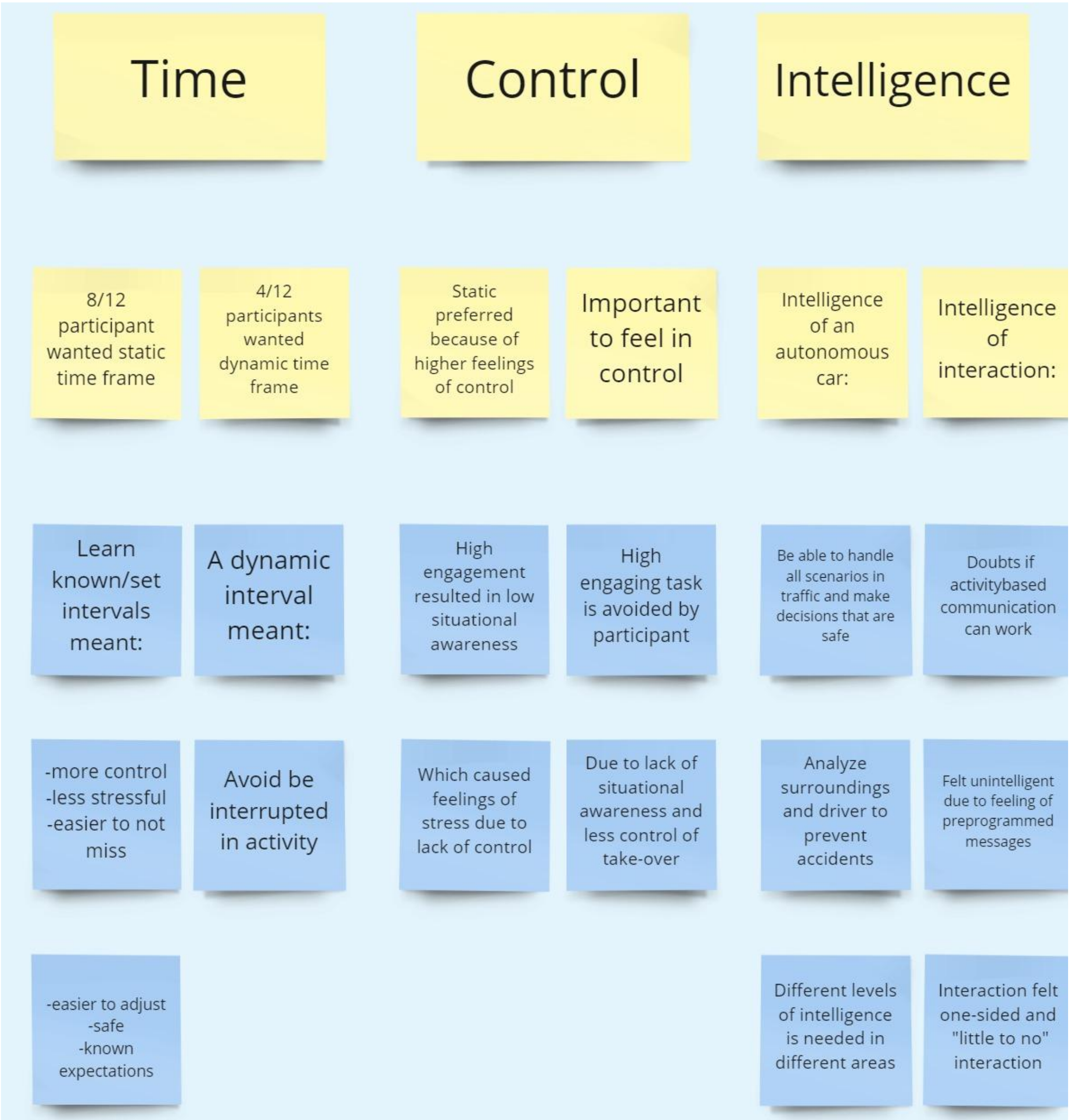
Translated: "If you could choose how the message of take over request would be performed: Would you 1. prefer to always receive the notifications of the TOR at the same time frame, no matter what activity you are engaged in? Or 2. would you prefer that the notifications would come at different time frames, which are adapted based on the activity you are currently engaged in? Describe more."

Original in Swedish: "Om du hade fått välja hur meddelandet om att ta över körningen skulle utföras: Hade du 1. tyckt att det var bäst att alltid få meddelanden under samma tidpunkt oavsett vilken aktivitet du utför? Eller 2. tyckt att meddelanden borde komma under olika tidpunkter, och därmed anpassas utefter den aktivitet du håller på med i stunden? Beskriv mer.

Appendix 13: Themes in in attitudes towards autonomous vehicles and engagement



Appendix 14: Themes in experience connected to Time, Control and Intelligence



Appendix 15: Time of the take-over

1st, 2nd or by the 3:rd TOR

Participant	Time frame	Take-over during Watching Video	Take-over during Building Lego	Completed assembling the Lego model
P1	Dynamic	1st	2nd	No
P3	Dynamic	1st	3rd	Yes
P5	Dynamic	2nd	2nd	Yes
P7	Dynamic	2nd	2nd	No
P9	Dynamic	2nd	3rd	No
P11	Dynamic	2nd	3rd	No
P2	Static	3rd	2nd (almost 3rd)	No
P4	Static	1st	1st	No
P6	Static	3rd	-	No
P8	Static	1st	1st	No
P10	Static	2nd	3rd	No
P12	Static	3rd	2nd (almost 3rd)	No

Appendix 16: SAM result during the Video activity

A: During the beginning of the activity

Participant	Time frame	Valence	Arousal	Control
P1	Dynamic	6	5	3
P3	Dynamic	9	5	8
P5	Dynamic	6	3	7
P7	Dynamic	7	3	5
P9	Dynamic	7	3	4
P11	Dynamic	6	3	8
P2	Static	8	3	8
P4	Static	5	7	3
P6	Static	6	3	8
P8	Static	3	6	1
P10	Static	8	3	6
P12	Static	7	6	5

B: The first notification of take-over information

Participant	Time frame	Valence	Arousal	Control
P1	Dynamic	7	6	7
P3	Dynamic	9	6	7
P5	Dynamic	6	4	7
P7	Dynamic	7	3	5
P9	Dynamic	7	5	4
P11	Dynamic	6	3	8
P2	Static	8	4	8
P4	Static	5	5	7
P6	Static	6	4	8
P8	Static	5	9	2
P10	Static	8	3	6
P12	Static	7	6	4

C: When taking over driving

Participant	Time frame	Valence	Arousal	Control
P1	Dynamic	7	4	9
P3	Dynamic	9	8	5
P5	Dynamic	6	6	5
P7	Dynamic	7	6	5
P9	Dynamic	5	6	5
P11	Dynamic	6	4	8
P2	Static	7	4	8
P4	Static	5	6	9
P6	Static	6	3	8
P8	Static	8	2	7
P10	Static	8	4	5
P12	Static	7	6	9

Appendix 17: SAM result during the Lego activity

A: During the beginning of the activity

Participant	Time frame	Valence	Arousal	Control
P1	Dynamic	7	6	6
P3	Dynamic	9	5	8
P5	Dynamic	7	5	6
P7	Dynamic	5	5	5
P9	Dynamic	7	5	7
P11	Dynamic	8	4	7
P2	Static	8	4	9
P4	Static	6	7	2
P6	Static	8	6	9
P8	Static	5	8	2
P10	Static	8	3	8
P12	Static	7	6	5

B: The first notification of take-over information

Participant	Time frame	Valence	Arousal	Control
P1	Dynamic	7	7	5
P3	Dynamic	9	7	8
P5	Dynamic	6	6	6
P7	Dynamic	5	6	4
P9	Dynamic	7	3	5
P11	Dynamic	7	4	7
P2	Static	7	7	6
P4	Static	4	8	2
P6	Static	8	4	7
P8	Static	4	9	1
P10	Static	8	3	7
P12	Static	7	6	4

C: When taking over driving

Participant	Time frame	Valence	Arousal	Control
P1	Dynamic	5	4	9
P3	Dynamic	9	8	7
P5	Dynamic	8	7	7
P7	Dynamic	4	8	3
P9	Dynamic	5	8	3
P11	Dynamic	5	7	4
P2	Static	6	6	6
P4	Static	3	5	9
P6	Static	6	9	2
P8	Static	1	5	3
P10	Static	7	6	4
P12	Static	7	6	9

Appendix 18: Post test questions with likert scale (1-9)

Lego activity

Participant	Time frame	Stressed	Mental Resource	Engagement
P1	Dynamic	7	7	7
P3	Dynamic	7	7	9
P5	Dynamic	7	6	8
P7	Dynamic	7	6	9
P9	Dynamic	8	7	8
P11	Dynamic	8	7	8
P2	Static	7	7	9
P4	Static	7	7	9
P6	Static	9	8	9
P8	Static	8	8	9
P10	Static	7	6	8
P12	Static	7	7	9

Video activity

Participant	Time frame	Stressed	Mental Resource	Engagement
P1	Dynamic	1	1	4
P3	Dynamic	2	1	2
P5	Dynamic	6	2	5
P7	Dynamic	6	5	8
P9	Dynamic	2	1	4
P11	Dynamic	2	2	6
P2	Static	2	2	8
P4	Static	3	6	3
P6	Static	3	3	2
P8	Static	3	2	2
P10	Static	6	3	5
P12	Static	2	3	3

Appendix 19: Mean score of the SAM scales for Valence, Arousal and Control

Video Dynamic	Time points of the test	Valence	Arousal	Control
	A	6.83	3.66	5.83
	B	7	4.5	6.33
	C	6.66	5.66	6.16

Video Static	Time points of the test	Valence	Arousal	Control
	A	6. 16	4.66	5. 16
	B	6.5	5.16	5.83
	C	6.83	4.16	7.66

Lego Dynamic	Time points of the test	Valence	Arousal	Control
	A	8	4.16	6.5
	B	6.83	5.5	5.83
	C	6	7	5.5

Lego Static	Time points of the test	Valence	Arousal	Control
	A	7	5.66	5.83
	B	6.33	6.16	4.5
	C	5	6.16	5.5

Appendix 20: Standard deviation of the SAM mean scores during take-over scenario: A, B and C for Valence, Arousal and Control.

Dynamic test group: STD of the mean score for SAM scales during both NDRAs

	VIDEO			**LEGO**		
	Valence	Arousal	Control	Valence	Arousal	Control
A	1,169	1,032	2,136	1,329	0,6324	1,0488
B	1,095	1,378	1,505	1,3291	1,643	1,4719
C	1,366	1,505	1,834	2	1,549	2,509

Static test group: STD of the mean score for SAM scales during both NDRAs

	VIDEO			**LEGO**		
	Valence	Arousal	Control	Valence	Arousal	Control
A	1,9407	1,861	2,7868	1,2649	0,6324	3,3115
B	1,3784	2,136	2,401	1,8618	2,3166	2,5884
C	1,1690	1,602	1,505	2,44948	1,471	3,0166