Faculty of Aerospace Engineering

Exploring Motion Sickness Mitigation in Self-Driving Vehicles with Anticipatory Interfaces

Flashing and Zooming over the Road: Anticipatory Interfaces Mitigate Motion Sickness

Wouter Jan Spek

26 April 2023

Delft University of Technology

Challenge the future

Exploring Motion Sickness Mitigation in Self-Driving Vehicles with Anticipatory Interfaces

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Master of Science Thesis

For obtaining the degree of Master of Science in Aerospace Engineering
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Department Of
Control and Simulation

The undersigned hereby certify that they have read and recommend to the Faculty of Aerospace Engineering for acceptance a thesis entitled **"Exploring Motion Sickness Mitigation in Self-Driving Vehicles with Anticipatory Interfaces"** by **Wouter Jan Spek** in partial fulfillment of the requirements for the degree of **Master of Science**.

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Acronyms

DUECA	Delft University Environment for Communication and Activation
FMS	Fast Motion Sickness scale
HMI	Human Machine Interaction
HREC	Human Research Ethics Committee
IMU	Inertial Measurement Unit
MISC	MIsery SCale
MS	Motion Sickness
MSAQ	Motion Sickness Assessment Questionnaire
MSI	Motion Sickness Incidence
MSSQ	Motion Sickness Susceptibility Questionnaire
NDRT	Non-Driving Related Task
OEM	Original Equipment Manufacturer
SRS	SIMONA Research Simulator

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Abstract

Motion Sickness in cars has recently been experienced by 46% of the population, according to a multi-demographic survey study. As self-driving vehicles are getting more realistic from a technical side, motion sickness is one of the factors that will make or break this technology and its societal benefits. Besides the optimization of driving style, informing a passenger of the next move has been found to help decrease motion sickness symptoms and increase comfort and trust. Some research did already show positive results, however, the best method or interface has not been found yet. This experimental thesis research will aim to compare two specifically designed acceleration-dependent analogue anticipatory interfaces in an identical setting. The experiment that is performed in the SIMONA Research Simulator, consists of three different trials: baseline, light interface, and a combined light and sound interface. Based on a small survey, subjects (n=18) are selected to participate in the triple trial within-participant experiment. Each trial lasts 30 minutes, has a static visual horizon, an identical route, and subjects are asked to select and read newspaper articles on a tablet. During each trial, subjects will verbally report their Misery Score rating during the trial and in the five minutes recovery period after. Data on effectiveness, intrusiveness, intuitiveness, trust, and preference of the interfaces will be gathered by means of an electronic survey after each session.

Chapter 1

Introduction

In today's world, a lot of processes are getting automated by ever-more advancing algorithms. Automation usually has a lot of benefits when performed at a large enough scale, such as improvements in predictability, consistency, efficiency, and safety. The automotive sector is aiming to make gradual automation steps on driving in the near future and this has the potential to bring a lot of societal benefits. However, there are still some issues to be solved before everyone will own a self-driving vehicle. Apart from legislation and general engineering improvements, there should also be a buyer incentive. It is inevitable that the first autonomous vehicles will come with a higher price tag and therefore the ability to spend your time doing Non-Driving Related Tasks (NDRTs) will be a big selling point, while this is very likely to decrease driving comfort with growing Motion Sickness (MS) symptoms.

1-1 Problem Statement

A large percentage of the world's population experiences Motion Sickness (MS) to some degree and the symptoms usually become worse when performing NDRTs [7]. Although there are some differences between different demographics, 45.6% of car users have experienced carsickness within the last five years according to an international survey [37]. Therefore the following problem can be stated:

Problem Statement

The high occurrence of Motion Sickness could negatively influence the use and therefore the societal benefits of autonomously driving vehicles.

The main reported causes of MS were categorized by: vehicle dynamics, smells or air quality, and visual activities such as reading [37]. As MS is a complex problem, there is not one way to solve it. Therefore the research field on MS and passenger comfort is quite broad. Much research is done to develop a prediction model that could be used to try to avoid MS triggers. This can be used as a tool to optimize vehicles for comfort or to be included in the cost function of the autonomous driving strategy.

1-2 Research Questions

The problem of Motion Sickness (MS) can be researched in several ways within the Human Machine Interaction specialization at the faculty of Aerospace Engineering. This thesis focuses on MS mitigation through the development of an anticipatory cueing interface, which leads to the first of the following research questions.

Research Questions

1. What type of anticipatory motion cueing interface design will be most relevant to the research field of motion sickness mitigation in self-driving vehicles?
2. To what degree can an anticipatory interface be a passenger-friendly tool to mitigate Motion Sickness (MS) in autonomously driving vehicles?
3. How do analog, directional light- and sound cues perform in terms of Motion Sickness mitigation and passenger experience?

The second question is about a combination of theory and practice and will be answered during the design of the interface and tested by experiment. The third and final question will be answered by the results of a human-out-of-the-loop experiment. To be more elaborate, detailed sub-questions have been set up. The literature sub-questions were answered before proceeding with the rest of the research. The sub-questions for the experiment were set up in line with the interface's (concept) design and were a follow-up to the conclusions of the literature questions.

Sub-questions Literature Study

1. What is the current research focus from the main car manufacturers to mitigate Motion Sickness regarding anticipatory interfaces?
2. Which factors have to be considered when designing a non-intrusive human-machine interface?
3. Which experimental results can have a contribution to the current research field of anticipatory cueing interfaces?

Research Questions

1. What type of anticipatory motion cueing interface design will be most relevant to the research field of motion sickness mitigation in self-driving vehicles?
2. To what degree can an anticipatory interface be a passenger-friendly tool to mitigate Motion Sickness (MS) in autonomously driving vehicles?
3. How do analog, directional light- and sound cues perform in terms of Motion Sickness mitigation and passenger experience?

The experimental sub-questions were set up after a prototype of the interface has been designed. They have been altered slightly, during the built and tuning of the experimental setup. As these questions will be answered by means of experiment, they will be concluded in the final thesis.

Subquestions Experiment

1. How much cue lead time feels the most intuitive to the passenger?
2. What is the effect of analog anticipatory light (L) or combined light- and sound (C) cues on the incidence and intensity of Motion Sickness compared to a baseline without an interface?
3. How do passengers experience analog anticipatory light (L) or combined light- and sound (C) cues in terms of comfort, trust, intuitiveness, and intrusiveness?
4. What are the differences between comparable analog light (L) or combined light and sound (C) cues in terms of Motion Sickness development and passenger experience and are they significant?

1-3 Thesis Structure

This research has a lot of connecting or dependent elements. The goal of the structure is set up to best understand the final experimental setup, rather than how this was reached. The research paper with the experimental results can be seen in Part I. This is a standalone paper, using internal referencing and its own bibliography numbering. All analyzed experimental results that were not discussed were placed in the Appendices of this thesis report.

Part II will discuss the relevant background and literature sub-questions, which will be concluded in Chapter 4. Part III will start with discussing the proposed Human Machine Interaction (HMI) design that is specifically designed to reduce MS. After this, the used hardware specifics and limitations were discussed as well as the experimental conditions with their reasoning. The experimental routine is discussed and detailed plans are placed in the appendices. As the experiment involves humans, it is discussed how the conditions are tuned to fit the subjective experience with the concept. This preliminary thesis ends with a discussion and conclusion focusing on the expectations of the experiment combined with the limitations.

Part I

Thesis Paper

Flashing and Zooming over the Road: Anticipatory Interfaces Mitigate Motion Sickness

Wouter Spek

***Abstract*—This study explored several anticipatory interfaces as motion sickness mitigation tool in autonomously driving vehicles. The interfaces were designed to lower the mismatch between the expected motion and the sensory input in a moving body, by providing anticipatory information on upcoming vehicle motion. The two proposed interfaces were a *Light* only interface and a *Combined* interface featuring both light and sound. The interfaces present information on the direction and magnitude proportional to the upcoming vehicle accelerations, 0.9s before the actual event. The interfaces were tested in separate trials and compared to a *Baseline* trial. The comparison was done by a mixed-order, within-participants experiment (n=18), performed in the SIMONA Research Simulator, with identical 30-minute driving conditions. To test the interfaces' effectiveness in the most motion sickness-triggering setting, subjects got a reading task on a handheld tablet. The results were quantified on an 11-point motion sickness scale and subjective survey questions. Improvements in motion sickness and subjective experience were found with both interfaces. However, only the *Combined* interface trial showed significant improvements compare to the Baseline. Neither of the interfaces was considered intrusive, while only the *Combined* interface was considered comfortable. The survey also clearly favored the *Combined* interface in scores on timing correctness, intuitiveness, and subjective cue correctness. Although the *Combined* interface had the best results, strong individual preferences were reported for both interfaces, a hypothetical sound interface, or no interface. Further research is advised to focus on the *Combined* interface while considering optional light and/or sound disengagement in line with personal preference.**

***Index Terms*—Motion Sickness Mitigation, Automated Vehicles, Anticipatory Interface, Driving Comfort, Sound Interface, Light Interface.**

I. INTRODUCTION

TRANSPORTATION is one of the drivers of our modern-day society. Therefore, it is relevant to continue improving this connecting sector. One of the developments in the automotive sector is the introduction of autonomous driving. Automating the full driving process allows for performance optimization on maneuvers and even full route planning. This creates a potential for vehicles to be optimized for low emissions, hardware conservation, traffic congestion, and many more. However, there are still some issues to be solved before everyone will own a self-driving vehicle. Apart from legislation and general engineering improvements, there should also be a buyer incentive. It is inevitable that the first autonomous vehicles will come with a higher price tag and therefore the ability to spend your time doing Non-Driving Related Tasks (NDRTs) should become a big selling point, while this is very likely to decrease driving comfort with growing Motion Sickness (MS) symptoms [1].

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A cross-demographic survey found that 45.6% of car users have experienced some level of MS in the last five years. The most commonly noted MS triggers identified were vehicle dynamics, smells, air quality, and visual activities such as reading [2]. Hence, the high occurrence of MS could negatively influence the use and societal benefits of autonomously driving vehicles.

Currently, different strategies are being researched to mitigate MS for passengers in autonomously driving vehicles. Some research is done on the prediction of MS, based on external inputs such as acceleration, as is done using the Six Degrees of Freedom Subjective Vertical (6DOF-SVC) model [3]. This prediction can be used to adjust the vehicle's driving behavior by design, or as part of active decision-making. However, not all motion that triggers MS can be practically prevented and passengers also have individual differences [4].

Another strategy is not to prevent the MS triggers but to help passengers to process them in a better way. This can be done by introducing better communication from the autonomous vehicle to the passenger(s). An interface can be developed, which can present information on the upcoming vehicle motion, that allows passengers to be better prepared. The next section will present its functioning theory as well as some early promising results. However, the field is still in an exploratory phase, which means it has many unanswered questions on a lot of options.

After a literature study on experiments with anticipatory cues, no clear interface type has been identified as best. There is often no clear reasoning behind the choice of interface and/or cue type. As most experiments vary too much for a valid comparison, a proper comparison between promising options could contribute to the research field.

The aim of this paper is to present the differences in performance of a *Light* and *Combined* (light and sound) interface as a MS mitigation tool and their subjective experiences. These two interfaces were tested under identical conditions and were both compared to a baseline as well as each other. The described research has explored different methods to do so and the following sections will discuss all relevant considerations of the developed concept in combination with an experiment to validate its functionality.

This paper starts with a concise background in Section II, followed by a description of the interface concept, described in Section III. This is followed by the validation method, experimental results, discussion, and conclusion of the experiment results (Sections IV-VII).

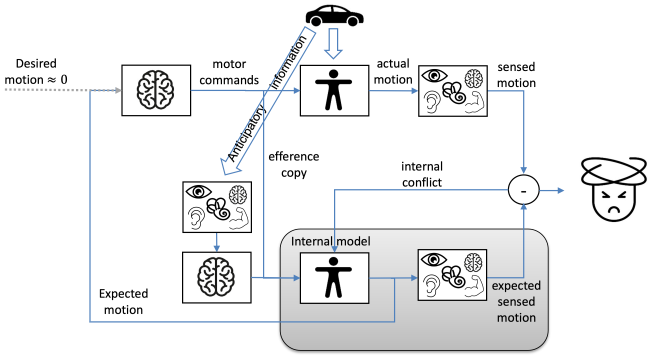


Fig. 1. Observer Model with Anticipatory Cues (adapted from [5])

II. Literature Background

As stated in the introduction, different techniques are used with the goal of reducing motion sickness. Much research has been performed on the prediction and anticipation of MS as will be discussed in this section. This paper focuses on using an anticipatory interface focused on MS mitigation. This section will discuss the theory and specific approach used for the designed anticipatory interface concept, after discussing comparable research. Lastly, this research will test the functioning and relevant considerations of a *Light*, and a *Combined* light and sound interface, of which the detailed workings will be explained in Section III.

A. Anticipatory Interface Workings

The interface concept discussed in the next section has been designed based on the working approach of the mathematical observer model [5] that is used to predict MS. In simplified terms, this model states that MS originates from a mismatch in short-term motion prediction from the internal model and the actual sensory input, which is visualized in a simplified manner in Figure 1. The desired motion in this figure is set to zero, assuming a passenger's passive posture. The internal model is trained to predict and anticipate inputs, with lower latency than the sensed input. The internal model is fed with the upcoming motor commands, called the *efference copy*, which are used to predict the upcoming body reaction and the accompanying sensory input that follows. In standing or walking conditions, the prediction is accurate enough, however, this mismatch grows when a sensory input does not match the motion. This is likely to happen in a moving body such as a car, as the inner walls do not provide any information on the vehicle's motion. An anticipatory interface should provide the internal model with the right information at the right time, to allow for a better prediction and thus a smaller mismatch. When looking at the observer model, it seems that the right information should be similar to the constant information stream from the *efference copy* for the required cognitive load to be minimal. This way, passengers should be able to (subconsciously) relate the cue and the motion, without the need for constant attention to the interface.

B. Research Field

Most public research is performed by universities in collaboration with an automotive company, which makes it likely that not everything is publicly available. This subsection will give a concise summary of the research that was found and used as the basis for the interface concept. As this is currently a very active research field, it is likely that this analysis misses the newest insights.

Volkswagen had successful MS mitigating results of an experiment using an ambient light interface on a test track [6]. The Mercedes-Benz group had similar results for longitudinal speed-dependent cues [7]. These cues were presented on white speed-dependent animated LED strips below and above the windows, that turned red during braking. Jaguar Land Rover has stated that they actively adapt driving to MS using biometric sensors[1], while also looking into the use of bone-conducted vibrations to use as anticipatory cues [8]. Ford has performed low-fidelity research on a textual sound interface in a moving cart [9]. Volvo focuses on discrete sound interfaces which also seem to have MS mitigating results [10]. They are not new to sound interfaces as they have also experimented with alarming drivers by panning stereo sound. This has been shown to decrease reaction times and increase comfort compared to conventional alarm interfaces [11].

Some other relevant examples include the use of discrete light cues to inform passengers of different types of vehicle actions, which are stated to increase trust and comfort [12]. As well as two very similar low-fidelity experiments with a moving cart. Hereby, discrete anticipatory sound cues showed MS mitigating effects [9], while discrete vibrotactile cues in the seat, were ineffective for several tested lead times [13].

C. Interface Considerations

MS is a complex reaction to many inputs in a world that contains many stimuli and even seat inclination has significant effects on MS [14]. To design a functioning MS mitigating interface, it is important to avoid confusing or ambiguous cues. It is also important to control variables that have an effect on MS during any MS experiment, such as the different types of stimuli and their timing.

1) Sensory Input: Although it is impossible to take all stimuli into account when designing any interface, it is important to be aware of the most important MS influencing factors. MS is considered to be most influenced by the vestibular and visual systems, as they play the largest role in human orientation. Other less influential systems are the auditory system, the somatosensory system, and the chemosensory system [2]. However, MS mitigation using smells like lavender and ginger was unsuccessful [15]. The highest MS incidence is created in a specific range of motion, with accelerations in every direction in the range of $0.1 - 0.3$Hz [16], [17].

2) Anticipatory Cue Timing: Anticipatory cues are supposed to present intuitive information at the right time for passengers to use the information for an improved internal prediction. Many experiments on MS mitigation with an

[1]https://www.jaguarlandrover.com/2018/preventing-motion-sickness
last accessed: 24-04-2023

anticipatory interface were performed under different circumstances and are therefore not comparable. No consistent use of timing was found. Experiments presented their anticipatory cues between 0.33 and 3 seconds before the actual movement [6]–[9], [18]–[21].

D. Light Interface

In order to work, a *Light* interface should always be in sight. Since passengers can freely move and look around in a vehicle, there should be a sufficient number of light sources to ensure there is always one in sight. Also, information should preferably be complete at every given moment in time, which removes the possibility of complex sequenced information. This means passengers would only miss information while closing their eyes, rather than misinterpreting information after opening their eyes as a result of missing a relevant part in such a sequence when they were closed.

The use of anticipatory light cues has been researched in several experiments that all presented results indicating improvements in either driving comfort or trust in autonomous driving [6], [19], [22], [23]. Most experiments used discrete cues, that did not indicate any intensity or duration of the vehicle's maneuvers. In a passenger Virtual Reality (VR) experiment involving the vehicle's reaction to a pedestrian crossing, comfort was equally improved when presenting intentions or perceptions of the outside on a light interface on the dashboard. Discrete light signals for left and right vehicle turns showed MS mitigating effects [19], however, this was less successful in a later similar setup [20]. It is clear that the perfect driving comfort-increasing interface has not been found yet. A more recent MS mitigating experiment presented continued speed-dependent animations on LED strips above and below the windows [7] (as mentioned in Subsection II-B).

Light-based interfaces have been used in vehicles for decades, therefore, it is important to avoid ambiguity in or outside the vehicle. Vehicle dashboards commonly indicate a warning with yellow and an alarm with red, which both would preferably be avoided to correlate with another type of interface. An external interface survey has shown that pedestrians have clear correlations with red for 'stop' and green for 'go', however, it was not clear if this signal was for the pedestrian or the vehicle itself [24]. Therefore, green should also be avoided as this can create dangerous situations, while cyan was indicated as a good neutral option. In addition, more general research has shown that color or intensity *changes* in a peripheral interface creates the best sense of awareness [25], which should be considered when designing an interface that passengers are not always actively looking at.

E. Combined Interface

The *Combined* interface adds a sound interface with a *Light* interface. By accident, Rolls-Royce engineers found out that removing all sound from a vehicle triggered so much disorientation in the test drivers, that they had to stop the tests.[2] This reversely proves that passengers or drivers use the existing vehicles' sounds for orientation to some degree.

Various strategies for anticipatory sound interfaces have been studied such as the earlier discussed cart [9], with verbal anticipatory information that lowered the MS response. A sound interface was also used to convey vehicle perceptions and intentions, increasing trust in autonomous driving in a VR experiment [10] (similar to the light interface of [22]), where various sounds were used, such as for identifying pedestrians and braking for traffic lights. Another experiment using an actual vehicle showed high passenger acceptance and MS mitigation, using single discrete cues for different maneuver types [18].[3]

For the experiment of this paper, the sound interface will be combined with the light interface. This is chosen over a sound-only interface, as the sound directions could be so poorly identified in the simulator, that it would not be comparable to the light interface. Sound cues generally give a fast but inaccurate response, while light cues create a more accurate, slower response. When combining the two, the benefits of both types of cues are combined, resulting in fast and accurate responses. The identification of objects in spatial orientation is done using both sight and hearing senses until the object is identified. Once identified, the brain will focus on both or only one of the senses [26]. Although this reaction is fast, a combined interface might be more intuitive than a single-sensory based interface.

Lastly, it is important to avoid any clashes with existing cues used for warnings or alarms. Therefore, the sound interface should avoid high-pitched cues or repeating patterns like the sound of an indicator.

III. Design Concept

Based on the above, a design concept was created that should increase driving comfort, by reducing MS. Design considerations were made such that the overall driving experience is improved. The general idea behind the interface is to provide information that can improve the short-term prediction of motion, thereby lowering the internal conflict and any related MS symptoms, as described in Subsection II-A.

A. Design Pillars

The main design philosophy is to develop an interface that has a positive effect on general driving comfort, by reducing MS. In order to narrow down the concept's design options, the following design pillars were chosen as a basis, with a concise explanation of practical implications:

- *Feasible:* The concept can be applied to the automotive consumer market, thus will have a high acceptance, is mass-producible, and is limited in cost.
- *Final solution:* not limited to experimental conditions.
- *Non-intrusive:* It will not contain handhelds, headphones, or extreme amounts or intensities of stimuli.
- *Low cognitive demand:* The information will be skill-based [27].

[2]https://edition.cnn.com/2020/09/01/success/rolls-royce-ghost-sedan/index.html *last accessed: 16-04-2023*

[3]Sound cues: https://youtu.be/YL-vrYbprjw *last accessed 17-02-2023*

- *Intuitive:* Passengers should not require a tutorial.

Apart from technical workings, the design aesthetics should be considered as well, as these can influence the interface's effectiveness, unrelated to its usability [28].

B. Motion-Cue Relation

The relationship between the vehicle's intentions and the anticipatory cues is mainly built up based on the workings of the observer model. The basic relations could be applied to several interface media, however, they are designed with the use of a sound and light interface in mind.

1) Information Type: As seen in Figure 1, the information should allow passengers to improve their prediction of the future vehicle and body motion with their internal model, to better align this prediction with upcoming movements. The information should preferably be at the skill-based, rather than a rule-based cognition level [27]. In line with this, the information should also be continuous/analog rather than discrete. Passengers should be able to (subconsciously) relate the cue with the vehicle motion, without requiring constant attention to the interface.

2) Proportional Relation: The continuous information of the concept is a simple relation between the (upcoming) horizontal vehicle accelerations and the interface cues. The experienced vertical accelerations during driving are very different, with a power spectral density peak at 1.8Hz when compared to 0.05Hz for horizontal accelerations [29]. This is a very different frequency than the peak of motion sickness incidence, which is around 0.2Hz [17]. It is unlikely that these accelerations cause significant MS, and therefore, vertical accelerations are neglected.

The *intensity* of the cue was made dependent on the acceleration's magnitude:

$$Cue_{intensity} = \frac{acc_{magnitude}}{acc_{max\_cue\_acceleration}} [\text{-}] \qquad (1)$$
$$\text{if } Cue_{intensity} \geq 1 \rightarrow Cue_{intensity} = 1$$

The upper bound is applied to avoid intrusiveness and an additional lower bound is used to filter out insignificant movements (see Table II). More extreme accelerations should be indicated by a warning, rather than a comfort-increasing interface. The *direction* of the cue will not go further than 90 degrees from the center front of the vehicle:

$$Cue_{direction} = \tanh \frac{acc_{lateral}}{|acc_{longitudinal}|} [\text{rad}] \qquad (2)$$

Therefore, the acceleration and deceleration have different cues to communicate the longitudinal direction. For the proposed simulator experiment motions described in Subsection IV-F, the following relation works well:

$$Cue_{type} : \text{if } acc_{longitudinal} \geq 0 \rightarrow \text{acceleration cue} \qquad (3)$$
$$\text{if } acc_{longitudinal} < 0 \rightarrow \text{deceleration cue}$$

However, this binary relation needs to be updated with smoother transitions for real-world driving scenarios. Relations (1)-(3) are sufficient to communicate the vehicle's horizontal acceleration vector. To make sure that the cues will work for all passengers in conventional and future concept vehicle chair layouts, all light and sound cues are mirrored to the back of the vehicle:

$$Cue_{back}(int., dir.) = Cue_{front}(int., \pi - dir.) \qquad (4)$$
$$\text{(mirrored to the back)}$$

This will ensure that a *Light* interface can be used without losing information when changing the viewing direction, by either looking around the vehicle or for passengers in a different seating orientation.

3) Filter: To adhere to the non-intrusiveness pillar, the cues should give a smooth experience. A smoothing filter is applied on both the magnitude and direction from Equations 1 and 2. The chosen filter is a central moving average, on the offline created cue commands, of which the time constant is chosen during the interface tuning sessions, as will be explained in more detail in Subsection IV-I.

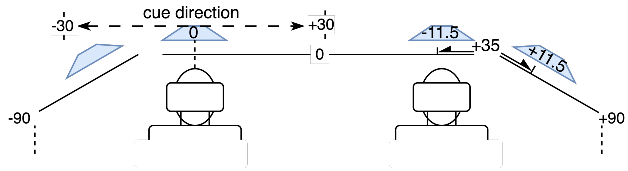


Fig. 2. Light Interface - cue placement (see Equation 5)

C. Light Interface

The *Light* interface should be able to present the full vehicle's horizontal acceleration vector, as passengers should be able to subjectively experience direction and magnitude. Furthermore, a *Light* interface has to be visual at all times from all viewing directions and the directional changes should stay within the visual field. The radial cues have to be presented in what is usually a rectangular-shaped vehicle. As this geometry has corners, it is relevant to consider symmetry around them. When introducing multiple light sources, direction ambiguity can occur after looking away or closing the eyes. This results in a cue placement as follows. The two corners in the front of the vehicle ($\pm 35°$) both have two sources ($\pm 11.5°$ from the corner), which are in directional range, proportionally decreased from $\pm 90°$ to $\pm 30°$. When a purely longitudinal cue ($cue_{dir} = 0°$) is presented, one light source is positioned in front of each passenger and another is positioned at an equal angle from the corner ($\pm 11.5°$). This is illustrated in Figure 2 and the precise angles used in the simulator can be constructed from the following pseudo-code relation:

$$\text{for } Cue_{direction} \text{ in range} : [-90°, +90°]$$
$$LightCue_{dir._{source\,1,2,3\&4}} = cue_{dir.} \frac{30°}{90°} \pm 35°(\text{corner}) \pm 11.5° \qquad (5)$$

The visualization of magnitude is done by changing both the brightness and the width of the cue. The approach is deliberately kept simple and scales the LED-width and RGBW code with the normalized intensity as in Equation 1. The

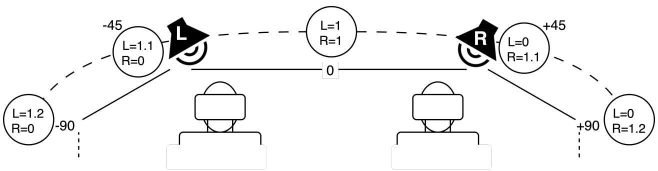


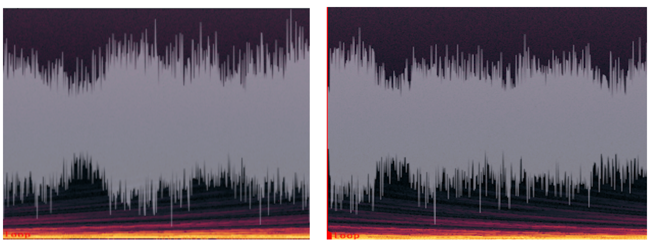
Fig. 3. Sound Interface - cue placement

color options are chosen to avoid misinformation in relation to existing signals or intuitively meaningful signals, as explained in Subsection II-D. The color choice and width range were chosen using tuning sessions as described in Subsection IV-I.

D. Combined Interface

The *Combined* interface combines sound cues with the light cues described in the previous subsection. For longitudinal accelerations, all speakers were aimed to be subjectively equally loud in this experimental setting. For the simulator, the rear speakers are 10% louder than the front ones. When the cue direction rotates away from the center, the opposite-sided speaker is linearly faded out between 0 and |30| degrees. On the other hand, the side of the cue direction will linearly get 20% louder between 0 and |90| degrees. This creates extra contrast between lateral and longitudinal accelerations.

The sound cues aim to give the subjective experience of acceleration or deceleration. This can be done by changing the frequency of a sound, similar to an engine. In order to ensure passengers do not confuse the sound interface with engine sounds, they should sound different. To make a sound interface that can give a continuous sound cue that is relatively constant, it has been chosen to use the Shepard's tone illusion that gives a frequency-changing sound experience [30]. The acceleration and deceleration sound profiles were designed in-house with digital synthesizer software. Both sound profiles are very similar as the deceleration sound is nearly identical to the acceleration sound played in reverse, are designed to be continuous (to be played in loops), and their sound spectrograms can be seen in Figure 4.



(a) Acceleration cue (b) Deceleration cue

Fig. 4. Sound cue spectrograms first 5 seconds

E. Test Requirements

To properly test this interface, some test requirements had to be identified. As the interface was designed to mitigate MS, it should work under the most triggering conditions. Aggressive driving, while reading, without looking outside includes three common triggers of MS [2] that can be used to test the concept. The driving pattern should not be predictable in order to test if subjects are using the interface's information rather than their own prediction. The same holds for the maneuvers themselves, as identical maneuvers result in identical anticipatory cues, which would make it impossible to prove that subjects understood the relation with the acceleration, as the cue could be interpreted as a discrete signal based on the maneuver. Therefore, the experiment's maneuvers must vary in timing, direction, and intensity. Furthermore, since driving comfort is a subjective experience, subjects should be asked to report their experiences by means of a survey.

IV. Method

A. Rationale

A within-participant human-out-of-the-loop experiment was performed to compare different analog anticipatory interfaces in terms of motion sickness mitigation and subjective experience. The two interfaces were designed specifically for the experiment, which involved three different trials on separate days with identical 30-minute motion profiles, a reading task on a tablet, and static visual conditions.

B. Independent Variables

The experiment aimed to compare the two designed interfaces with a *Baseline* and each other. In order to test this, three separate trials on separate days were conducted with identical motion and either no interface (*Baseline*), a *Light* interface, or a *Combined* light and sound interface.

C. Control Variables

To ensure that subjects were reminded of the same details on all three trial days, the same verbal experiment briefing was repeated before each trial. At the start of each trial, subjects were made aware of which trial (*Light* interface, *Combined* interface, or *Baseline*) they were about to experience, to avoid the search for other inputs. The chair was adjusted for each subject, to keep the head position constant, while the back inclination was kept constant. All three experiment trials had the same reading task, simulator lighting, simulator motion, and a static base vehicle engine sound. The engine sound did not change during the trial and was mainly there to mask the sound of the simulator hydraulic motion actuators, especially during pre-positioning, which should not be any part of the subjects' experience.

D. Participants

Participants were invited by means of posters spread around the campus and networking. The invite referred to an electronic survey of which the replies were used to select participants, based on the Motion Sickness Susceptibility Questionnaire-short (MSSQ-short) [31], age, and gender. It also included practical information about the experiment and practical questions on planning. Selected participants were invited by email with additional information. Out of the male-dominated 43 reactions, 18 participants were selected such

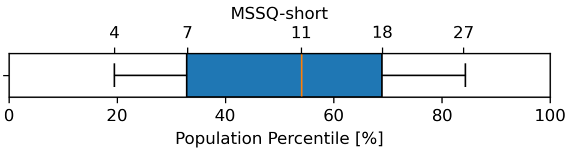


Fig. 5. Selected participants (μ = 11.63/52.66p.perc., σ = 6.65/19.78p.perc.)

that an equal male-female ratio was met, with similar age and population-representative MSSQ-short values. Most subjects were searched in and around the university, resulting in an average age of 23.3 years (σ = 2.92 years). All participants stated that they did not suffer from any vestibular or (uncorrected) eye impairments.

The main selection goal was to avoid extremely (non)susceptible participants. The final MSSQ spread of all subjects is shown in Figure 5.

E. Experimental Procedures

Each subject conducted all three trials within a maximum of eight days. A minimum of one rest day was included between each trial. This rest day became a soft requirement if subjects had low MS susceptibility in the first trial (which occurred three times). Subjects were asked to show up well-rested and limit their alcohol (and other drug) intake 24h prior to each trial. It is expected that participants learn from previous trials, therefore, participants are mixed into all six possible orders, to mitigate order effects. However, with 18 participants, there were only 3 participants per specific order.

The experiment briefing informed subjects about the planning, communication procedures, measurement types, posture preferences, and the reading task on a tablet. The newspaper could possibly lead to concentration changes in correlation with changing daily headlines. Although striking headlines could create biases, this correlation is individually dependent on interest, which would to some degree be with every possible (reading) task. Subjects received a ten euro voucher as compensation for each participated trial, for which completion was not required.

After the first briefing, participants signed a written *informed consent*, before proceeding. The data management plans were checked by the faculty's data steward and the entirety of the experiment including general measurements and simulator procedures have been approved by the Human Research Ethics Committee of the TU Delft. Before each following trial, the full briefing was repeated. Participants were told about the trial types and which one they would experience, without further explanation. This should have lowered their need to search for unrelated inputs.

Participants got an elastic head strap with an IMU on their forehead, were informed to take a relaxed posture, and were asked to limit unnecessary large head movements during the 30-min drive. During the trial, a '*ping*' sound was played every minute, after which participants verbally reported the highest Misery Scale (MISC) score (see Subsection IV-J) state they have experienced since the previous measurement. The answers were written down by the researcher, including any comments. The measurement frequency was doubled in the first five minutes and the five minutes of recovery after the drive. The biggest changes were expected in the first five minutes, after which the measurement frequency was lowered to avoid too much distraction from the reading task, which did not matter for the five minutes after the drive. The experiment or a trial could have been terminated by the participant at any given time. If a third six or a single seven MISC score was reached, the researcher terminated the trial. Subjects were not informed of this threshold. After each trial, participants were given the option to take a break, after which they were seated for an electronic survey.

TABLE I
MOTION PROFILE INPUT & RESULTING MANEUVER VARIABLES

Maneuver Design point		Stop and Go	Defensive Corner	Aggressive Corner
amount	#	20x	10xL/10xR	10xL/10xR
deceleration max	m/s^2	-2.94	-2.26	-3.92
acceleration max	m/s^2	2.26	1.67	3.14
side acceleration max	m/s^2	-	2.94	4.41
side jerk max	m/s^3	-	4	2
max point decel./accel.	s	3.1 / 2	4.2 / 2.5	2.0 / 1.9
m decel./accel. [32]	-	4.7 / 0.6	6.1 / 0.55	3.8 / 0.85
V_{maneuver}	m/s	8.3	8.6	9.4
Radius (arc length)	m (deg)	∞	20 (70)	25 (70)

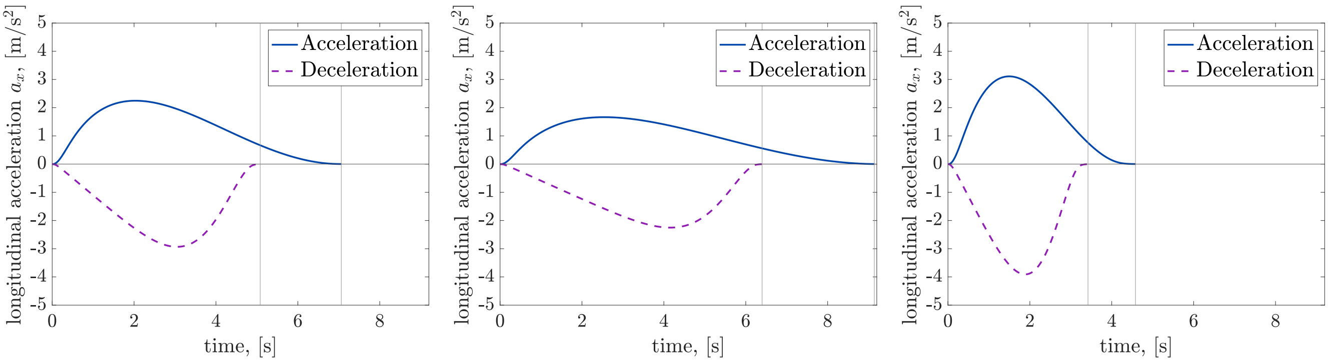
F. Experimental Condition Design

Participants experienced a 30-minute route with 60 maneuvers of three different types in seemingly random order, with a static outside horizon. During each trial, subjects were asked to read the news[4] at their own pace and preference on a browser of a 10-inch tablet with a brightness of 65%, with the simulator cabin light turned off. With the aim to reduce focus around the tablet, the brightness was chosen to be relatively high. Most pages had a similar light background and contained text as well as images.

To test the working theory of the interfaces, the experimental conditions followed the requirements as discussed in Subsection III-E. In order to be unpredictable, it is important to vary all information the interfaces are supposed to present, namely: *timing, direction, and magnitude*. Furthermore, autonomous vehicles will likely be designed to avoid MS-triggering acceleration profiles. But to test our interfaces, the acceleration profiles were deliberately designed to have more extreme accelerations than expected during normal operation.

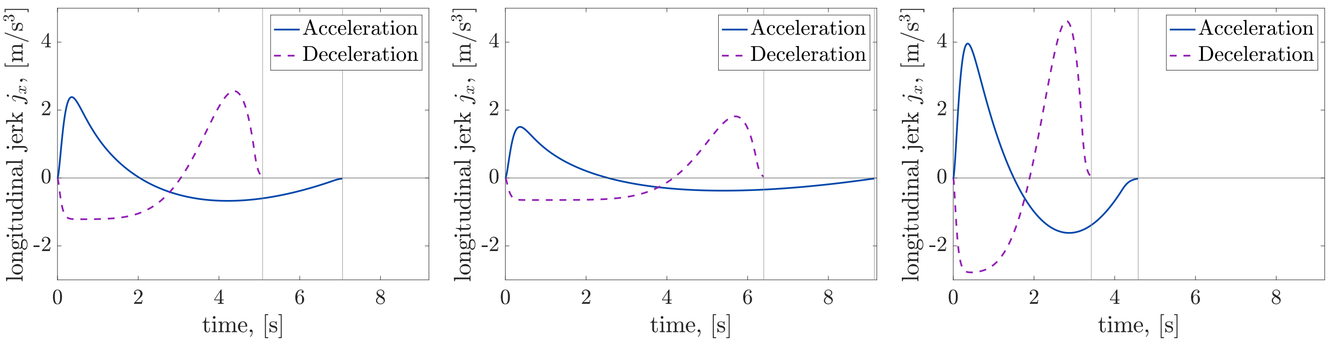
The motion profile starts with an acceleration and ends with a deceleration, with 60 maneuvers in between. On straight parts in between the maneuvers, the vehicle drives 60km/h (16.67 m/s), however, since a static view is used, subjects will not be able to perceive any speed. The focus was thus on accelerations as the speed becomes arbitrary, which allowed a 'stop and go' maneuver that does not stop. Furthermore, the cornering maneuvers transition to the corner radius with a clothoid defined by the maximum jerk values of Table I.

[4] www.nytimes.com



(a) Stop and go (b) Defensive maneuver (c) Aggressive maneuver

Fig. 6. Longitudinal acceleration profiles from the different maneuvers



(a) Stop and go (b) Defensive maneuver (c) Aggressive maneuver

Fig. 7. Longitudinal jerk profiles from the different maneuvers

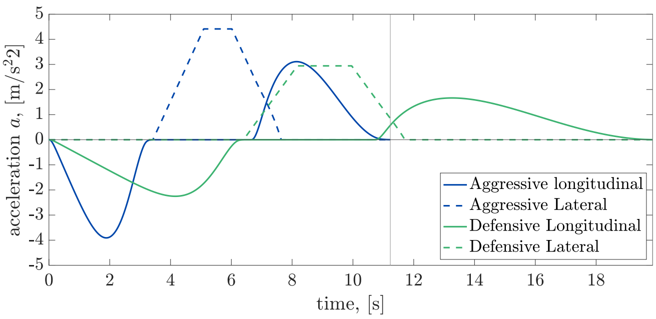


Fig. 8. Full acceleration profile of corner maneuvers (different time-axis)

The different characteristics of the chosen maneuvers (Table I), are chosen to represent real driving conditions [19], [33]. These characteristics were used to generate the profiles offline using a kinematic polynomial acceleration model [32], with the defining function as follows:

$$a(t) = ra_m\theta^n(1-\theta^m)^2(n = 1.0) \tag{6}$$

$$r = \left(1+\frac{n}{2m}\right)^2\left(1+\frac{2m}{n}\right)^{n/m} \tag{7}$$

Where $a(t)$ is the longitudinal acceleration at time t in m/s^2, a_m is the maximum acceleration in m/s^2, and θ is the ratio of time over the acceleration curve. As recommended, n = 1, and the values for m were chosen to fit the acceleration maxima points in Table I.

To ensure smooth driving, a low-pass filter was applied with different time constants for the longitudinal directions:

$$H_{acc}(s) = \frac{1}{(\tau_s s+1)^2} \quad (\tau_{s_{acc.}} = 0.1\text{s}, \tau_{s_{dec.}} = 0.05\text{s}) \tag{8}$$

The three acceleration profiles and accompanying jerk profiles are presented in Figures 6 and 7. The cornering maneuvers increased with the given jerk value to a constant side acceleration and also decreased linearly until the acceleration increases the speed, as seen in Figure 8. Here, it can also be seen that the lateral acceleration follows directly after the longitudinal deceleration, while the longitudinal acceleration started one second before the end of the lateral acceleration. This was done to improve driving fidelity.

The full 30-minute drive consists of 60 maneuvers, with pseudorandom order and intervals (in the range of (8-20.5s). The maneuvers and timings are mixed up to create the need for anticipatory information, compared to a predictive scenario. The maneuver timing was forced such that the MISC measurement could always be performed on a ‘straight’ part of the route. For this measurement, subjects have to verbally report their MISC score in reaction to a ‘ping’ sound. This timing was chosen to avoid inconsistent measurements and to make sure the ‘ping’ sound did not interfere with the *Combined*

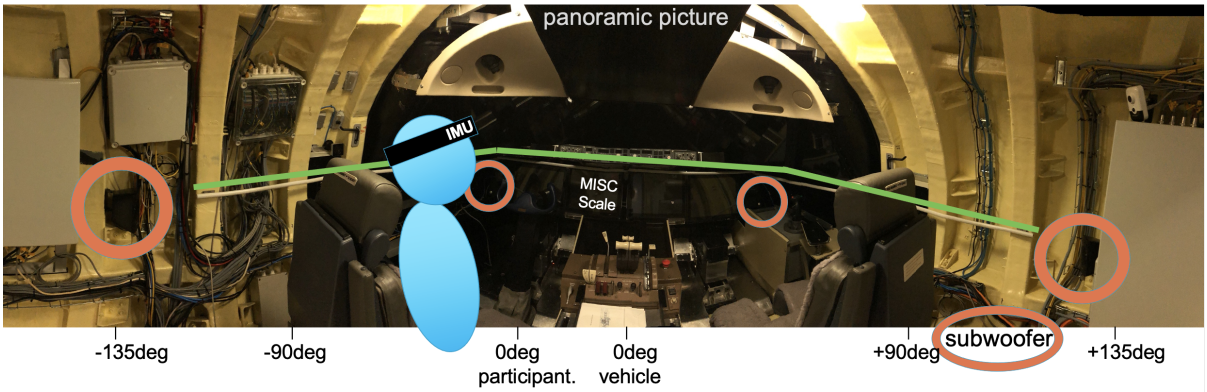


Fig. 9. Panoramic representation of the simulator setup (green: LED-strip; brown: speakers)

interface cues. To avoid too much repetition, the maneuvers were capped to a maximum of two subsequent maneuver types and three subsequent turning direction repetitions.

G. Apparatus

The experiment was conducted in the SIMONA Research Simulator (SRS) of the TU Delft. The SRS has a 6-DOF hydraulic hexapod motion platform. Participants were seeing a static horizon on a 180°×40° collimated screen with infinite depth of field. The artificial horizon splits the gray ground and a blue sky with a simple white line and was kept constant to limit visual inputs and their effect on the experienced MS. Furthermore, the cabin light was turned off and subjects only got light influx from the 'outside', a screen at their front right with the used MS scale (MISC) and the *Light* interface (if applicable). The interface placement can be seen in Figure 9.

Both interfaces were designed to present similar information. They are different to account for the differences and limitations that each of the medium types has, as described in the previous section.

1) Light Interface: The concept as described in Section III-C is a 360° LED strip to ensure the interaction in every direction. However, for this experiment setting, a 270°(± 135°) strip was deemed to be sufficient, as participants should look forward. The interface used is thus a semi-surround, individually addressable 60LED/m SK6812 RGBW LED strip controlled by a *Teensyduino 4.1*. To ensure a more organic experience, a blur strip has been added. The vertical placement has been chosen to represent a position just below the window.

2) Sound Interface - Combined Trial: The *Combined* interface trial is identical to the *Light* trial, with the addition of the sound interface. The SRS has a central sub-woofer and speakers in four corners that were individually controlled. A handheld measured 60dBA on the straights, consisting of background noise and a static motor sound, while the maximum cue volume in the aggressive corner was measured at 77dBA. The 'ping' sound that indicated a MISC score measurement, produced 64dBA.

H. Motion Cueing

The simulator motion cueing was done *offline* and was identical for each trial type. The SRS has a limited motion space

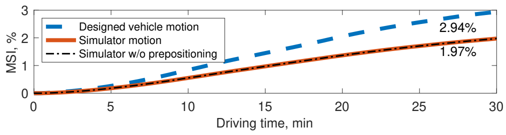


Fig. 10. MSI prediction of the full route with the 6DOF-SVC model

and therefore the designed acceleration profiles could not be identically performed. The motion was scaled with a factor K and a first-order high-pass filter was applied:

$$H_{HP}(s) = \frac{s}{s + \omega_{n_{HP}}} \tag{9}$$

To mimic sustained linear accelerations, a second-order low-pass filter was applied to the tilt coordination:

$$H_{LP}(s) = \frac{\omega_{n_{LP}}^2}{s^2 + 2\zeta_{LP}\omega_{n_{LP}}s + \omega_{n_{LP}}^2} \tag{10}$$

Here, $\omega_{n_{HP}}$ and $\omega_{n_{LP}}$ represent the high-pass and low-pass filter break frequencies in rad/s, respectively, ζ_{LP} represents the low-pass damping ratio. The participants' head placements were aimed to be identical, such that these tilt illusions work correctly. Furthermore, they experienced movement as they would in the left-hand front seat of the vehicle, which is 0.4m to the left of the vehicle's center line.

During the preparation of the experiment, several settings were tested for motion fidelity. The final combination of filter settings that the tests converged to are K = 0.38, $\omega_{n_{HP}}$ = 2.5 rad/s, $\omega_{n_{LP}}$ = 2.5 rad/s, and ζ_{LP} = 1.0, with the tilt coordination angular rate limited to 2.1 deg/s.

To enlarge the simulator's horizontal motion space, pre-positioning has been applied before every maneuver. Pre-positioning accelerations were generally kept below 0.034 m/s^2 but had one instance of 0.049 m/s^2 in the last minute. This is slightly higher than the reported 0.04 m/s^2 human vestibular threshold [34], but has been used in similar experiments without being actively noticed. The final motion profile was run through the 6DOF-SVC model [3] to get a predictive indication of the MS response during the experiment. The final motion profile results in a Motion Sickness Incidence (MSI) of 1.97%, as can be seen in Figure 10. Here, it can also be seen that the MSI is not affected by the pre-positioning motion. This final value is small, but comparable to previous similar

TABLE II
INTERFACE VARIABLES RESULTING FROM THE TUNING SESSIONS

Variable	Unit	Chosen Value
Lead time	s	0.9
$K_{\text{direction}}$ central moving average	s	1.51
$K_{\text{magnitude}}$ central moving average	s	1.51
Color: acceleration	RGBW	[20 190 75 5]
Color: deceleration	(4x 0-255)	[254 0 140 0]
min cue acceleration	m/s^2	0.2
max cue acceleration	m/s^2	4
pixel width min-max	$\#_{pixels}$ (cm)	3-40 (5-67)

experiments [35]. They were chosen to be on the lower side, as the reading task was expected to increase MS susceptibility.

I. Anticipatory Cueing

All cues were generated offline as described in Subsection III-B. The three trial types are identical apart from the activation of an extra interface. The described design has been tested and iterated to fit the conceptual description of the subjective experience. This was done by performing several tuning sessions with concept-informed subjects. Table II presents the main tested interface parameters that were chosen by converging from a range of test options. The lead time (0.9s) was tuned while both interfaces were activated.

The *Light* interface is able to clearly present both magnitude and direction. However, the sound system setup of the SRS is not able to clearly present from which lateral direction the cue is coming. This is a result of sound reflection from the hard shell without sound isolation. During the experiment, subjects only experienced the sound interface in combination with the *Light* interface and have therefore always been able to construct the full acceleration vector.

J. Dependent Measures

This list states all the measures that were taken at various moments of the experiment:
(**1**) *Motion sickness susceptibility*: Prior to the trial, as part of the selection process, participants' individual motion sickness susceptibility in comparison to the general population was determined using the MSSQ-short [31].
(**2**) *Motion sickness scores*: The motion sickness during the trials was tracked on a 1-min interval according to the Misery Scale (MISC) score [36], which rates MS until vomiting on a 0-10 scale. Subjects were instructed to report the highest score experienced since the last measurement. The precision increased to 30s intervals for the first five minutes during and the five minutes after the simulator motion.
(**3**) *Post-trial survey:* Participants got a trial-dependent electronic survey at the end of the three trials. The order within each Likert-style question group (3b/c/d) was randomized and each question had a counter-question. The full questions are in Appendix A. The questions were analyzed per pair. In addition, each question group had room to leave comments.
(**3a**) *Motion sickness symptoms*: After each simulator run, participants indicated if they had experienced any of 24 commonly experienced symptoms on a four-point ordinal scale.
(**3b**) *Motion questions:* After each simulator runs, participants got 5-point Likert-scale questions on driving style, comfort, reading focus, drive realism, MISC measurement distraction, and body response to movements.
(**3c**) *Interface questions:* After the simulator runs with one of the two interfaces, participants answered questions on clearness, comfort, motion-cue relation, trust/correctness, intuitiveness, intrusiveness, and timing correctness.
(**3d**) *Comparison questions:* After the last simulator run, participants answered questions on interface preference, comfort, light vs. combined, and how driving styles were perceived differently between trials.
(**4**) *Head movements:* An IMU strapped to the forehead of the participant measured all free accelerations and rotations of the head movements. (outside of the scope of this paper)

K. Data Analysis

Similar to comparable experiments, with a terminated trial, the last MISC value was used for all remaining data points [35]. It is likely that order effects had an influence on the results, however, the analysis focuses on the combined results of all mixed order of participants per trial type.

To check for significant differences in MISC scores between the trials, the individual last ten-minute average MISC values were run through a non-parametric Friedman test and Related-Samples Wilcoxon Signed Rank test. When individually comparing the *Baseline* to both interface trials, the Bonferroni correction needs to be applied, requiring $p < 0.05/n$ for significance, where $n$is the number of hypotheses tested on this data set. The last ten-minute average was used rather than the last value as these values are more relevant to the research goal and are more precise than a single discrete MISC result.

Each of the subjective questions had a counter question to check for answer consistency. To quantify this consistency, a Cronbach's Alpha test [37] was performed on each question pair, split per trial type. A value higher than 0.7 proves an acceptable answering consistency (0.8 is good), which suggests a correctly constructed question pair. Furthermore, to test the Likert scale questions, the question and inverse of the counter-question were averaged. A t-test was then performed on the average answer.

L. Hypotheses

The workings of the designed interfaces were tested by means of the described experiment. As the experiment was performed with the *Light* and *Combined* interfaces, the first two hypotheses were individually applied to both interfaces.
H1L & *H1C* - The experienced motion sickness of the interface trials will be less than the *Baseline* trial:

- Measured by *MISC* difference with the *Baseline*

H2L & *H2C* - The general subjective driving experience will be improved by using an interface:

a Measured by interface *comfort* from the survey,
b Measured by interface *intuitiveness* from the survey, and

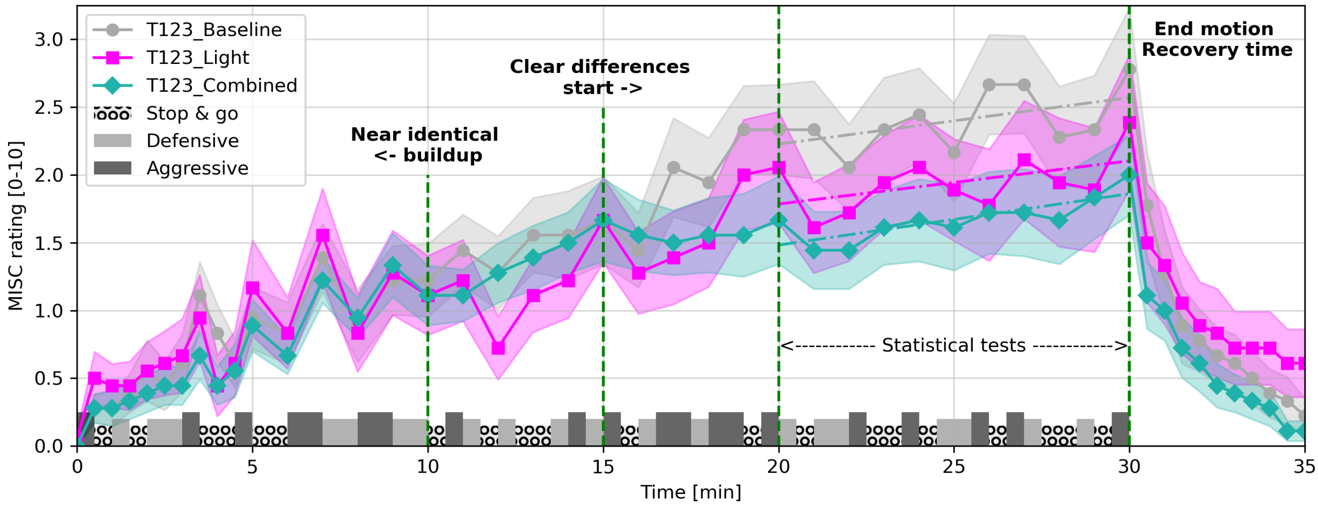


Fig. 11. Total averaged MISC score per trial type with standard error and linear fit for the last 10 minutes (the gray bars indicate maneuver timing)

c Measured by interface *intrusiveness* from the survey.

H3 - The *Combined* interface will perform better than the *Light* interface:

a Measured by *MISC* difference and

b Measured by interface *intuitiveness* from the survey.

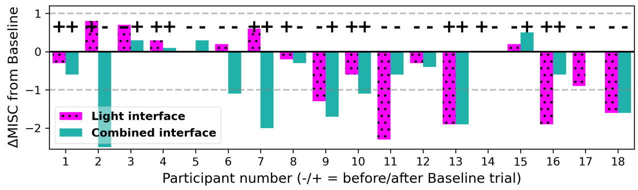


Fig. 12. Individual $\Delta\text{MISC}_{last10min\ average}$ compared to the *Baseline* trial

V. Results

A. MISC

Figure 11 shows the averaged MISC scores per interface type trial for all eighteen participants. The identically colored area around each data point indicates the standard error and a linear line was fitted through the data of the last ten minutes. Some insusceptible participants sporadically reported a MISC score of 1 first half and a considerably stable 1 for the second half. These values lowered the average results and have a larger influence on the lower averages of the first half of the drive as a result of the discrete scale. The visible fluctuations are mostly correlated to the different maneuvers, of which the timings are indicated. The 'stop & go' maneuver has the smallest effect, even though it does not have the lowest longitudinal accelerations. This difference can either result from the use of lateral accelerations or from the difference in maneuver length, as these also shorten the straight path lengths around them. The results of the *Combined* interface trial had a smaller reaction to these fluctuations, compared to the other trial types, which suggests that subjects are less affected by or could better anticipate the maneuvers.

After fifteen minutes, the interface trials show clear trends of improvements compared to the *Baseline* trial. Hereby, the *Combined* interface trial shows the biggest and most stabilizing improvements. As this research is about the decreasing general MS development, rather than direct motion reactions, the analysis was focused on the last ten minutes of the drive.

1) ΔMISC - Interface Trials Compared to the Baseline: Figure 12 illustrates the participant differences in MISC score, also indicating if the *Baseline* trial was before (**-**) or after (**+**) the indicated trial. These presented values are an average of the last ten minutes of motion, where negative values result from improved (lower) MISC scores. When averaging all participants, the improvement for the *Light* and *Combined* interface trials compared to the *Baseline* trial are -0.47 and -0.73, respectively. When performing the analysis over the full 30 minutes, the improvements are smaller, with -0.26 and -0.37, for the *Light* and *Combined* interface trials, respectively.

2) Statistical Analysis: As described in Subsection IV-K statistical tests were applied to the individual MISC score averages of the last ten minutes of the drive (indicated in Figure 11). The first tests in Table III, comparing all three trial orders and trial types, both do not have statistical significance between all trial types and orders. When analyzing the order effects with Wilcoxon signed-rank tests between trial numbers, it was seen the second trial mainly creates this difference. The improving difference between trials one and two is not significant ($Z = -1.734$, $p = 0.083$), which is reversed with increasing data difference between trials two and three ($Z = 2.131$, $p = 0.033$). This difference becomes insignificant when using the Bonferroni corrected significance threshold ($p < 0.05/n$). Although the value of n could in this case argued to be 2 or 3, both values result in insignificance. Moreover, since the differences between the first and third trials are minimal ($Z = -0.104$, $p = 0.917$), these order differences are more likely to come from individual biases (see Figure 12) than from order effects due to learning. When comparing the different trial types, the *Light* interface trial seems to have the largest contribution to these order differences.

The results of the Wilcoxon signed-rank test for the other hypotheses can also be seen in Table III. H1C, which tests the MISC difference between the *Baseline* trial and the *Combined* interface trial, shows a clear significance including the Bonferroni correction. The results of the *Light* interface are in between both other two trial types and therefore it has smaller differences from the other trials. This results in the rejection of both H1L, when compared to the *Baseline* trial, and H3a,

TABLE III
STATISTICAL TESTS LAST 10MINUTES AVERAGE MISC (N=18) AND LIKERT INTERFACE QUESTION Q5 FROM FIGURE 16

Input	**B-L-C**	**T1-T2-T3**	**B-L**	**B-C**	**L-C**	**L-C (Q5)**
Test	Friedman (df=2)		Wilcoxon signed-ranks			
χ^2 / Z	4.906	5.281	-1.683	-2.484	-0.882	1.747
p	0.086	0.071	0.092	0.004	0.378	0.081
Test	types	orders	H1L	H1C	H3a	H3b
Result	-	-	failed	passed	failed	failed

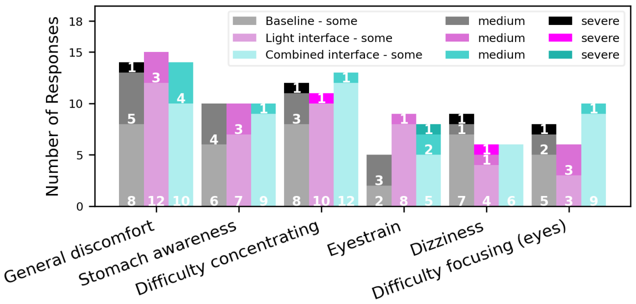


Fig. 13. Most recorded MS symptoms per trial type (selection)

when compared to the *Combined* interface trial. Although both comparisons are insignificant, the results of the *Light* interface are closer to the MISC score improvements of the *Combined* interface trial than they are to the *Baseline* trial.

B. Motion Sickness Symptoms

A selection of the six (out of 24) symptoms was made, based on the highest occurrence on all last trials, and can be seen in Figure 13. The results are added on an ordinary scale. Although the results did not show any weird biases, this selection excludes fatigue, as participants were not in a controlled environment between trials This symptom could have been strongly influenced by external factors. Most subjects' did not have all three trials at the same time of the day, which could also have influenced these results.

At first glance, the frequency of the experienced symptoms did not change much between the trial types, however, the level at which they were experienced changed. The *Combined* interface trials had only one instance of a *severely* experienced symptom: eyestrain. The symptoms were experienced most severely in the *Baseline* trials, while the *Light* interface trial results are in between the results of both other trial types. This is in line with the MISC results from Figure 11.

C. Subjective Preferences

The last survey included several questions on preference. In general, subjects preferred an interface over no interface. Figure 14 presents the answers about subjects' preferences. The first two questions identically asked which trial they experienced as most comfortable, however, before answering the second question, subjects were informed about the trials' identical motion. This resulted in a shift towards the *Baseline* trial, mainly from the *Light* interface trial. This suggests that

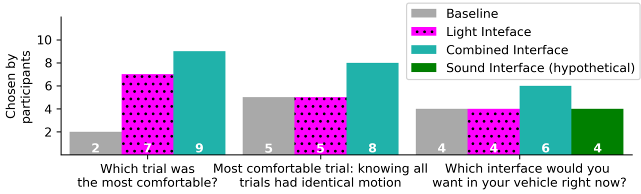


Fig. 14. Trial and interface preferences

subjects experienced different driving styles with an activated interface. The two subjects that preferred the *Baseline* trial before being informed, also stated this trial had the least aggressive driving style.

In response to the question on the experienced driving style difference between the trials, four subjects correctly experienced the trials' motions to be identical, four experienced all of them differently, four identified the *Combined* trial as the odd one out, and the other six were divided on the *Baseline* and *Light* trial to be the odd one out.

Furthermore, the survey answers in Figure 17 also indicate clear preferences for the use of an anticipatory interface (Q1). Most subjects indicate that the interfaces improve general driving comfort (Q2). At last, Q3 indicates a more or less evenly divided preference when comparing the *Combined* interface with the *Light* interface trial, slightly skewed to a preference for the *Combined* interface trial.

D. Survey Output

The survey questions are presented per trial type and can be seen in Figures 15, 16, and 17. The question pairs were reordered for better visualization. Therefore, the upper questions should agree in line with the hypotheses. All questions are listed in Appendix A.

Most subjects experienced the simulator drive as unrealistic, which may have affected the results. Most answers for both interfaces are in line with the expectations and the results of the *Combined* interface have slightly better in the direction of the Hypotheses and answering consistency.

To use the survey results to prove the defined hypotheses, T-tests have been performed on the relevant question pairs. These tests compare the Likert result [-2,2] to a normal distribution with a neutral mean [0]. All relevant outputs are presented in Table IV, with a comparison of *intuitiveness* in Table III. These tests are stand-alone and therefore do not require the Bonferroni correction. However, they should be analyzed with caution as the interfaces should not only give a good experience but should also be an improvement to a drive without an interface (*Baseline* trial), to be in line with the design philosophy.

As a validity check, subjects were asked if they could focus on the reading task (Figure 15 Q2). This was consistently agreed with, for all trial types, even though some comments were made about the *Combined* interface being distracting. The question about bodily reactions (Q5), does not show any conclusive results and was often stated to be confusing, however it was not removed from the results for completeness.

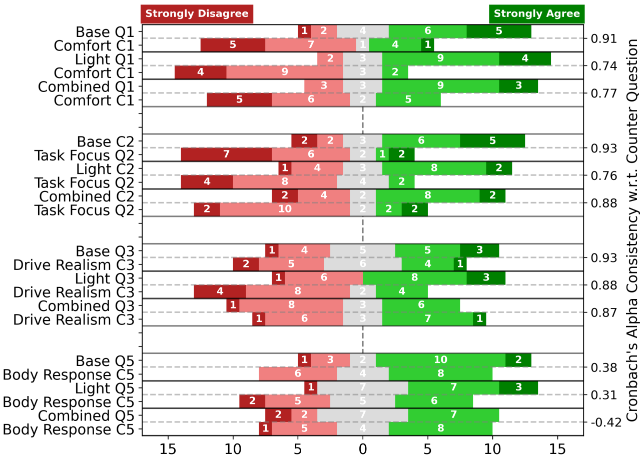


Fig. 15. Survey answers from each trial (questions in Table V)

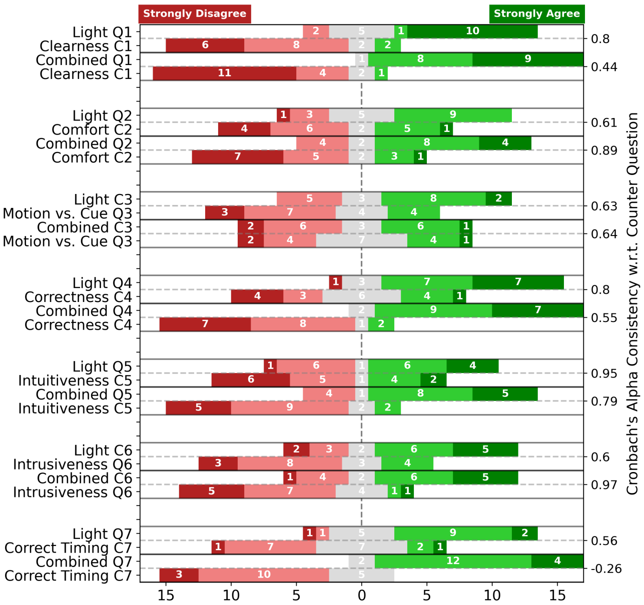


Fig. 16. Survey answers from interface trials (questions in Table VI)

VI. Discussion

A. General Results

Although all results are in the direction of the stated hypotheses, not all are statistically significant. The *Combined* interface trial gives significantly better results than the *Baseline* trial in terms of MISC score (H1C), experienced comfort (H2Ca), intuitiveness (H2Cb), and intrusiveness (H2Cc), but is not significantly better than the *Light* interface in terms of MISC (H3a) and intuitiveness (H3b). Although the *Light* interface does see consistent improvements compared to the *Baseline*, apart from intrusiveness (H2Lc), the results are generally not significant (H1L, H2La/b). The *Combined* interface has significant improvements on MS (Table III) and most survey questions have a stronger significance and stronger consistency between the question pairs.

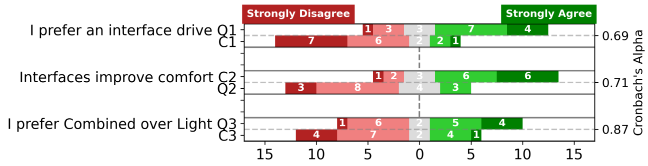


Fig. 17. Survey answers from last survey (questions in Table VII)

TABLE IV
T-TESTS ON LIKERT [-2,2] QUESTIONS 2/5/6 IN FIGURE 16

Input	**Comfort (Q2)**		**Intuitiveness (Q5)**		**Intrusiveness (Q6)**	
	L	C	L	C	L	C
μ	0.139	0.722	0.417	0.861	0.528	0.667
σ	0.997	1.141	1.364	0.936	1.036	1.188
t (17)	0.591	2.687	1.296	3.902	2.162	2.380
p	0.562	0.016	0.212	0.001	0.045	0.029
Test	H2La	H2Ca	H2Lb	H2Cb	H2Lc	H2Cc
Result	failed	passed	failed	passed	discussion	

It is important to remember that these individual tests all describe different elements of the interfaces. Interfaces can still be an improvement in driving without having a 100% pass on all individual elements. Furthermore, Subsection VI-C describes how the *Baseline* trial might have optimistic results, as some participants found the simulator sounds of the hydraulic actuators during pre-positioning useful as anticipatory information in the *Baseline* trial. This would mean that some *Baseline* trials have similar MS mitigating effects as the interface trials. Therefore, results compared with the *Baseline* are likely to be on the pessimistic side as the trial was not fully experienced without anticipatory information.

1) Driving Comfort: A relevant result, in line with the design philosophy about comfort, is that both interfaces do not decrease driving comfort. For the t-test on the comfort of the interface (Q2 Figure 16), the *Combined* interface trial has significant results (Table IV), combined with high question-pair answering consistency (0.89). This is a lot higher than the consistency of the *Light* interface trial results (0.61). As can also be seen in Table IV the survey results for the comfort of the *Light* interface trial are not significant. In general, the significance of these answers should be looked at with the necessary caution, as the *Baseline* trial was also considered to be comfortable as can be seen in Q1 Figure 15. However, subjects did indicate a comfort increase with the use of an interface in the trial comparison questions (Q2 Figure 17).

2) Intuitiveness: Although every interface requires some learning, one of the design pillars was set up for the interfaces to be intuitive for the end-user as it would not be preferable to require any form of tutorial before use. A t-test for the question about intuitiveness (Q5 Figure 16) only gives a significant result for the *Combined* trial. However, for a complete analysis of the intuitiveness of the interface, the answers to questions on clearness, correctness, and timing correctness should also be used (Figures 16).

For both interfaces, nearly all subjects identified a clear relationship between the cues and the accelerations (Q1). However, while the correctness of the *Combined* interface was not questioned (Q4), subjects did agree a bit less on the correctness of the relation of the *Light* interface with the motion. At last, the timing correctness should be analyzed. The timing has been tuned during the testing phase of the experiment, which resulted in a cue lead time of 0.9s (+0.75s filter) with respect to the upcoming horizontal acceleration vector. Although this was a fixed variable during the experiment, subjects were asked about timing correctness (Q7), which can be used as validation. Hereby, there were no subjects that disagreed with the timing of the *Combined* interface, however, subjects were more neutral about the *Light* interface. This could be explained by the different reaction times to light and sound impulses [26]. Sound cues were found to generally have a less accurate, but faster response time than light cues. Therefore, the *Light* interface might have performed better with a slightly larger lead time, of at least 0.1s more [26]. Subjects have also been reported to combine these fast and accurate results when using an audiovisual interface, which could also be an explanation of the performance difference of the *Combined* interface.

Based on these results, it seems that the current chosen lead time favors the *Combined* interface. Therefore, the insignificant results of the *Light* interface trial's intuitiveness, might be a result of a created bias. A different lead time might have more intuitive results and therefore this is not a conclusive result. Nonetheless, the intuitiveness of both interfaces could potentially change with the introduction of more impulses such as engine sounds or changing light from outside. Therefore, the interfaces should be tested in a high-fidelity setting in an actual vehicle, before drawing any conclusions on the real-world interfaces' intuitiveness.

3) Intrusiveness: A reduction of MS can be a great improvement as long as the mitigation method is not equally annoying. Therefore it is very relevant to consider the perceived intrusiveness of both interfaces, based on Q6 (Figure 16). Luckily, the subjects' answers show significant results (Table IV), proving both interfaces to be *un*intrusive in this setting, compared to a neutral normal distribution. The *Combined* interface has the strongest significance and a much higher question pair answering consistency (0.97) than the *Light* interface (0.6). These results can be supported by the indifference between all three trials in task focus (Q2 from Figure 15), as this focus would have likely decreased during interface trials if they would have been experienced as intrusive.

B. Preference

Figure 17 clearly indicates that most subjects preferred the use of an interface and that it increases their comfort. Subjects have identified their interface preferences in several ways as can be seen in Figure 14. Interestingly, there are three subjects with a preference (Figure 14) for the *Light* interface while having the best MS response in the *Combined* interface trial. The preferred was often the trial in which subjects experienced the least extreme driving behavior. However, after telling subjects that all drives were identical (Figure 14) , this correlation disappears. This suggests that subjects can have an unconsciously improved driving experience with an interface they might not directly prefer.

Comments: For each question category, participants were allowed to leave additional comments to clarify their answers. As some closed answers can be interpreted in several ways, the comments could be used to explain the answers. From the comments, it became clear that the interface preference is very personal. There is no clear relation found between interface preference and MS susceptibility. Some subjects, with both small and large MS responses, stated that the interfaces were very distracting and therefore did not prefer any interface.

Many comments were made about the increased drive intensity of the *Combined* interface trial, as well as some about the *Light* interface trial. Although some also stated that the driving fidelity increased with the activation of the interfaces, especially with the use of the *Combined* interface, this is not backed by the answers on experienced driving realism (Q3 Figure 15). It is likely that the differences in driving realism and/or intensity are linked to a lack of normal driving cues like engine sounds. When compared to the *Baseline*, the light interface trial and especially the *Combined* interface trial have more cues that may feel comparable to normal driving cues.

C. Experiment Improvements

A perfect experiment is highly improbable, especially with human subjects. Although the full experiment was tested and iterated before the first measurement trial, some faults or practical limitations were likely to have influenced the results.

1) Simulator Sounds: To test the interface concept with the use of a surround stereo, as would be realistic to use in a vehicle, participants did not wear noise-canceling headphones as is common practice for the simulator. The interface concept is vehicle-fixed which complicates the use of headphones on a head that can move and rotate with respect to the vehicle. Headphones would also not comply with the *non-intrusive* design pillar. As a result, some participants noticed the sound of the simulator's hydraulic actuators and stated to have used these sounds during pre-positioning movements throughout the *Baseline* trail as anticipatory cues. Although these sounds were identical for every trial, they were mainly noticed after subjects had experienced an interface trial, after which they were used as a replacement for missing anticipatory information. This could have influenced the analyzed order effects discussed in Subsection IV-K, as the *Baseline* results improved with the trial number, which could also just have been due to learning effects. If the interface worked as expected, the MISC results of the *Baseline* trial are likely to be lower than a true baseline trial should have been, as subjects might have used the discussed sound consciously or unconsciously. Although some directional sound information would have been lost, this could have been mitigated by using headphones and increasing the stereo's volume.

2) Experiment Planning: Experiments with multiple trials involving humans in uncontrolled environments between trials are bound to have different initial conditions as a result of external factors. Although most factors are not feasible to control, different planning might have helped as some differences have been commented on and/or observed between participants that had trials on different parts of the day, e.g.

trial one in the morning and trial two, two days later in the afternoon. This effect is very likely to be influenced by the circadian rhythms [38], which affect factors like alertness and reaction time. This could have created biases unrelated to the trial type, for subjects that had trials on different parts of the day, even though the aim was to plan the subject's three trials at similar times. Although this adds planning complexity, these possible biases could be mitigated by planning all three trials of an individual subject at identical or similar times.

D. Concentration

Although all results are in the direction of the hypotheses, it is essential to consider all possible alternative causes of the observed MS mitigation improvements from the *Baseline* trial. The results of the survey question on subjects' motion awareness versus interface awareness (Q3 Figure 16) leave room for alternative workings of the interface. The interface is designed to work by reducing internal conflict, by presenting the upcoming vehicle motion. However, it is known that MS susceptibility changes with a passenger's attention [7], [14]. For the *Combined* interface trial, half of the subjects reported that they were more aware of the interface stimuli than they were aware of the motion (Q3 in Figure 16). This could mean that the *Combined* interface had the most MS mitigating results because it functioned as the best distraction, rather than the best anticipatory interface type.

If the MS mitigating results are indeed a result of a successful distraction, this could have undesirable long-term effects. Humans are very good at learning how to filter out distractions and could thus learn to ignore the interface's information. If the interface indeed relies its functioning on distraction, then the interface's effectiveness is likely to decrease over time.

E. Future Work

The interface concept has proven its workings for a small participant group in a controlled setting. However, the concept needs further testing before concluding its functioning is successful. Future experiments should preferably be performed with the *Combined* interface in an actual vehicle on a test track as the driving fidelity of this simulator experiment was considered low (Q3 Figure 15). It is important to check if the concept still works in normal driving conditions that include actual engine sounds and outside visual stimuli. Although the *Combined* interface shows the best results in this experiment, light-only or sound-only versions should still be considered in further research, as this experiment found clear individual preferences. Therefore, based on these preliminary results, a suggestion for a final application would be to develop the *Combined* interface with optional individual disengagement of the sound and/or light interfaces.

VII. Conclusion

This paper investigated anticipatory interfaces as a tool to mitigate motion sickness without decreasing driving comfort.A human out-of-the-loop experiment was performed in which two interfaces, a *Light* and a *Combined* light and sound interface, were compared with a baseline in three separate trials with identical motion. The overall results of the designed interfaces are in line with the design goals and hypotheses. All results should be interpreted with care, as the driving fidelity of this experiment was limited. Participants generally had the best scores in terms of motion sickness, comfort, and intuitiveness with the *Combined* interface. Based on preference results and comments, there are clear individual differences in preference for a *Light* interface, a *Combined* interface, a hypothetical sound interface, or no interface. Further research should prove the *Combined* interface's functioning in a setting with higher fidelity. Although this interface has the most promising results, the individual preferences of light and sound should be taken into account.

Acknowledgment

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Appendix A
Full Survey Questions

Each trial ended with filling out an electronic survey. This appendix presents the full written out questions, that are linked to the keywords as used in Figures 15, 16, and 17, a well as Tables III and IV.

TABLE V
LIKERT QUESTIONS AFTER EACH TRIAL

Keyword	Survey Questions
Comfort	Q1: The ride was comfortable C1: I had an unpleasant drive
Task Focus	Q2: I could not focus on my reading task C2: It was easy for me to concentrate on my reading task
Drive Realism	Q3: The simulator motion felt like an actual car drive C3: The movements were not representative of a real life drive
MISC Distraction	Q4: Having to provide the MISC score regularly distracted me a lot C4: I did not feel distracted by the need to provide the MISC score
Body Response	Q5: I noticed that my torso/neck anticipated on the movements in time C5: My torso/neck muscles only had a (later) correcting reaction to the movements

TABLE VI
LIKERT QUESTIONS AFTER INTERFACE TRIALS

Keyword	Survey Questions
Clearness	Q1: I saw a clear relation between the motion and the lights/sounds C1: The lights/sounds did not seem to be correlated with the movements
Comfort	Q2: The light/sound interface made the drive more comfortable C2: My comfort of the drive was decreased by the light/sound interface
Motion vs. Cue	Q3: I was more aware of the light/sound interface than of the motion C3: The motion was more prominent than the light/sound interface
Correctness	Q4: I trusted the information from the interface to be correct C4: I was uncertain if the interface was giving consistent and/or correct information
Intuitiveness	Q5: I quickly knew how to interpret the light/sound information C5: It took me a long time to understand how to interpret the information from the light/sound interface
Intrusiveness	Q6: The light/sound interface felt very intrusive C6: The light/sound interface did not annoy me
Correct Timing	Q7: The timing of the lights/sounds was perfect C7: The timing of light/sound information should be earlier or later

TABLE VII
LIKERT COMPARISON QUESTIONS AFTER FINAL TRIAL

Keyword	Survey Questions
I prefer an interface drive	Q1: I prefer a ride without an interface C1: I would prefer a ride with such an interface
Interfaces improve comfort	Q2: The ride itself felt more comfortable with an interface C2: The interface had a negative effect on the ride comfort
I prefer Combined over Light	Q3: I prefer the light interface over the combined light/sound interface C3: I prefer the combined light/sound interface over the (only) light interface

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Part II

Literature Study

(This part has been graded for the AE4020 Course)

Chapter 2

Motion Sickness

Motion sickness is a well-researched but poorly understood phenomenon. There are many parameters that affect a person's experience of motion sickness. In order to design proper mitigation, all inputs a passenger can receive must be considered. According to a survey by Schmidt et al. [37], apart from the different direct inputs, passengers from different age groups or origins experience different levels of motion sickness. This chapter will discuss all the influences on the passengers that were considered during this exploratory design research.

2-1 Human Orientation

The human body can experience the world around itself through a wide range of sensory inputs. Many neural inputs from different senses working together can create a sense of orientation. An important part of this orientation is the direction of the subjective vertical, which is the subjective experience of the gravitational force and thus the direction of the ground (Bos and Bles [9]). The subject-relevant part of each sensory system is explained in this section, primarily based on Bear and Seung [3] and Borst et al. [8].

Sensory Organs

Motion Sickness is a very complex problem that is affected by many different inputs. The external inputs are perceived by the following sensory systems:

- Vestibular
- Visual
- Auditory
- Somatosensory (muscles state and skin)

Humans can detect acceleration in six different axes with the vestibular system. The Otoliths and Semicircular canals can detect linear and angular acceleration, respectively. These organs can these states by using the mass inertia of a heavy fluid (endolymphe), which has a slight lag with respect to the body [3]. This way, the experienced specific forces can be translated into nerve signals that will go through several steps of processing in the central nervous system and will eventually be used to keep the body in the preferred position.

The eyes are the sensory organs of the visual system and are used for a wide range of functions. Apart from navigation and expectations, the visual system can provide less complex information for orientation. The eyes can directly provide information on translation and rotation, followed by combined effects like expansion/contraction and more complex movements. This gives another important input for e.g. balance.

The somatosensory system is able to provide information on the tension in each muscle group, which, combined with the correct cognition, can be used to orientate the body with respect to gravity or the main acting forces on the body. This information can be further supported by skin pressure senses.

The auditory system can be used for spatial orientation. The ears are shaped such that they distort sound frequencies from different directions to identify the direction of the sound source. By integrating these inputs, people can identify head rotations with respect to sound sources or reflecting surfaces such as walls. However, since this research focuses on passengers in a vehicle's enclosed space, this type of orientation can not be used. Furthermore, most deaf people do not suffer from MS [13]. This is likely to be a result of a badly functioning vestibular system that is often accompanied by a lack of hearing. Thus, when designing an inclusive interface, it would not be required to include options for deaf passengers.

Low Level Cognitive Processing

Balancing the body is usually not a conscious process, but happens rather automatically. All relevant inputs are processed as fast as possible without the use of active cognition. Some even faster processes are in place for basic reactions, making this skill-based behavior. This is very important to keep in mind when designing an interface that could potentially mitigate MS. As an example, a continuous skill-based task, should not be combined with a rule-based interface. Therefore interfaces using speech, text, or other skill based information should be avoided.

Chemosensory System

Although it is not used for orientation, it has been shown that the chemosensory system also has an impact on motion sickness [37]. "Bad" smells can increase MS incidence. It has been tried to mitigate MS, using the introduction of different smells like lavender and ginger by Schartmüller and Riener [35]. However, the performed experiment did not provide any significant improvements on MS symptoms.

2-2 Observer Model

Motion sickness was firstly defined by Irwin [21] as: "*irritative hypercemia of the semicircular canals.*" The subject has been extensively researched ever since but is considered to be a complex problem with many parameters involved. There are very clear differences per individual and even per demographic (Schmidt et al. [37]). This makes it very important to use experimental results with the possibility of experimental biases in mind.

One of the leading theories on the cause of MS is described as a conflict in the internal observer model by Oman [31], as can be seen in Figure 2-1. This model starts with a desired motion, which can be stationary, that is translated by the brain into motor commands to the body. An *efference copy* of these motor commands is also fed into a trained internal model that is able to predict the body's response. This expected response is used as feedback for following body commands, which is a lot faster than waiting on the information from the sensory organs for feedback, thus increasing the response time. The information from the internal model is also used to predict expected sensory input from external input. In a perfect scenario, the external sensory input is equal to the expected sensory input. However, the human orientation system is not perfect. In an enclosed vehicle, there is not always visual input to movement, which will create a conflict between expected and actual sensory input, when the vehicle is experiencing accelerations. It is considered that this **'internal conflict'** is the biggest contributor for the experienced Motion Sickness.

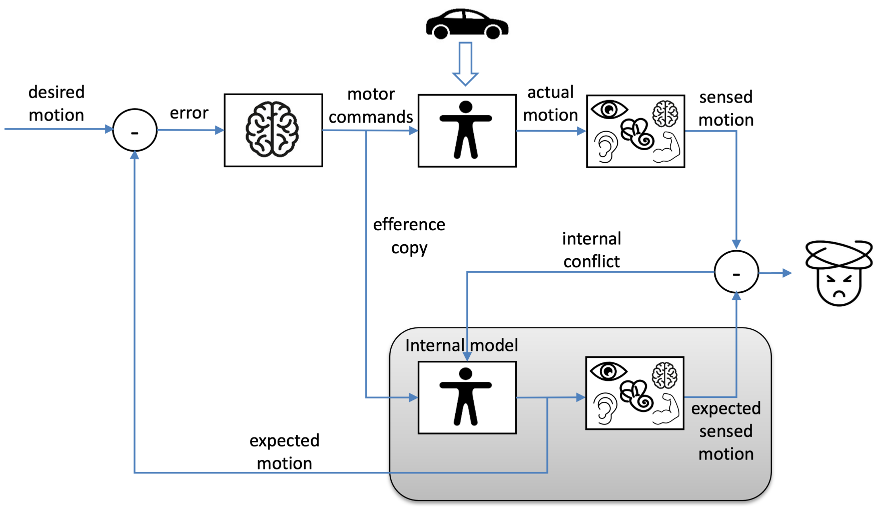


Figure 2-1: Simplified Observer Model (Oman [31])

As a passenger in a driven vehicle, this desired motion input to the observer model is mostly passively sitting. When the vehicle starts to move, the external inputs get significantly different than the planned movement as the body has to correct for movements it did not plan by itself. For simplicity, as a passenger, the desired motion can be removed from the control loop. This makes the scenario very different compared to an active driver, as here the driver plans the motion and is trained to understand and anticipate to the vehicle's reaction. As this usually results in a smaller internal error, this is likely to be the reason why drivers usually do not get Motion Sickness.

2-3 Motion Sickness Measuring

The feeling of discomfort or nausea is a human sensation that can not be expressed in objective units. Therefore another scale has to be used in order to be able to express and compare the results of an experiment involving MS. The most broadly used scales in this research field are the Fast Motion Sickness scale (FMS) by Keshavarz and Hecht [23] and MIsery SCale (MISC) by Bos et al. [10]. There is no clear preference for either method, as long as they are used consistently. In this research, the MISC rating is used as the measuring method of choice. This method is chosen as it has enough precision but is also not too large to cause large variations in subjective interpretation. The scale can be seen in the table below:

Table 2-1: Misery Scale Rating

Symptoms		MISC
No problems		0
Some discomfort, but no specific symptoms		1
Dizziness, cold/warm, headache, stomach/throat awareness, sweating, blurred vision, yawning, burping, tiredness, salivation, no nausea	Vague	2
	Little	3
	Rather	4
	Severe	5
Nausea	Slight	6
	Fairly	7
	Severe	8
	(near) Retching	9
Vomiting		10

In order to get an idea of a participant's self-rated MS susceptibility, the Motion Sickness Susceptibility Questionnaire (MSSQ) by Golding [18] can be used as a metric. This is a survey with questions about previous experiences with MS. As MS is very dependent on the situation and subjective experience, this is not the most trustworthy metric. However, the MSSQ can be used as a tool when looking for biases or outliers.

2-4 Autonomous Driving Scenarios

This research specifically focuses on experiencing MS in autonomous driving vehicles. This makes it much different than MS as experienced in aircraft or boats. Therefore, some assumptions can be made about nominal conditions. As an example, the accelerations are mostly in the horizontal plane. The median acceleration power spectral density spectrum for vertical acceleration peaks around 1.8Hz. While both the longitudinal and lateral acceleration peak around 0.05Hz [14]. This shows that vertical accelerations are probably more experienced as vibrations, rather than large movements.

In general, it can be said that most movements are directly related to actions by the vehicle's control or dynamics. The road can be assumed to be flat and stationary in most scenarios, which makes it different than boats or aircraft that experience a lot more external input noise. As has been stated, other research on MS mitigation investigates the effects of all accelerations on the experienced MS. By doing this, critical acceleration-based triggers can be identified and efforts can be done to avoid them in normal driving behavior. With this in mind, the assumption can be made that autonomously driving vehicles, that are designed with MS mitigation in mind, will have comfortable driving behavior in normal operation. As extreme acceleration and jerk and generally experienced as non-comfortable, these will not be likely to occur in normal operations. This can be kept in mind while designing an interface.

Apart from the driving behavior, another assumption can be made based on the general shape of a vehicle. Since cars are not that large, it can be stated any possible passenger's position of not very far away from the center of the vehicle. As a result, it can be assumed accelerations are very similar in the entire vehicle as accelerations caused by rotations are generally small. Although this is generally the case, road inputs like speed bumps are significant enough to break this assumption. During speed bumps, vertical accelerations are experienced differently in the front and back as the vehicle rotates as well as translates. However, in general, accelerations can be assumed as being similar. Therefore a centrally placed car-fixed reference frame can be an accurate indication of accelerations as experienced in the rest of the vehicle. This still holds when different seating orientations are applied, as can be seen in some concept vehicles.

Non-Driving Related Tasks

The amount of MS that a person experiences is not only affected by inputs from the road. MS susceptibility can also be affected by the activity of the passenger. Bohrmann et al. [6] has presented differences in the preference for four different tasks: watching a movie, performing a quiz, reading a text, and playing a game on an iPad (n=24). One of their results is that high (subjective) concentration levels were correlated with low MS symptoms while using the Motion Sickness Assessment Questionnaire (MSAQ). This concentration also played a role in their task preference. Watching a movie and doing a quiz were considered to be the most pleasant as these activities required the lowest concentration. Most participants found reading and playing a game the most unpleasant.

2-5 Experimental Setting

In order to research this topic it is important to understand how research equipment affects an experiment's result. The effect on the motion sickness of different simulators has proven insignificant. Klüver et al. [25] performed experiments on the different types of moving or static simulators of Mercedes. The research compared moving base simulators in two directions and three types of fixed base simulators. Two fixed base simulators were in a vehicle, with a flat and surrounding screen for outside visual respectively. The third simulator just had the dashboard and an outside view, without the rest of the vehicle. The research concluded that the simulators provoke a comparable amount of MS when using the same visual information.

Chapter 3

Anticipatory Cues

This chapter will dive into the research performed in the field of anticipatory cues revolving around autonomously driving vehicles. This is one of the methods that is believed to be promising as an active MS mitigation strategy. The information presented is split into an Original Equipment Manufacturer (OEM) research summary and information on different types of interfaces. This is done for clarity and will have some form of redundant information.

3-1 Anticipation Display

Motion sickness is not fully understood. Most older research suggests, that the problem is mainly caused by a mismatch between visual and vestibular perception. However, there are clear indications that the expectation of those perceptions plays a far larger role [44]. This expectation is usually made by external inputs from the visual system or other sensory organs that contribute to spatial orientation. When looking back at the observer model in Figure 2-1 and removing the desired motion (as discussed), it becomes clear that the system is incomplete or at least has a certain delayed reaction.

In order to compensate for the lag in the control loop, it is clear that information has to be added to create a better prediction. Assuming that the body's state is controlled by feedback from the internal model, it sounds reasonable to feed these external inputs into the internal model. This can be done by feeding cues to one of the sensory organs, that can be interpreted as useful information to feed into the internal model. As discussed, this should be skill-based information, as extra cognition requires extra time and concentration. By creating a cognitive intervention, the expected body state better aligns with the perceived body state. In order for this to work, the person should be able to intuitively see or learn a clear and direct relationship between the anticipatory information and the upcoming motions. This learning is preferably an unconscious process, as this would result in fewer fluctuations in concentration. The relation can be seen in Figure 3-1 on the next page.

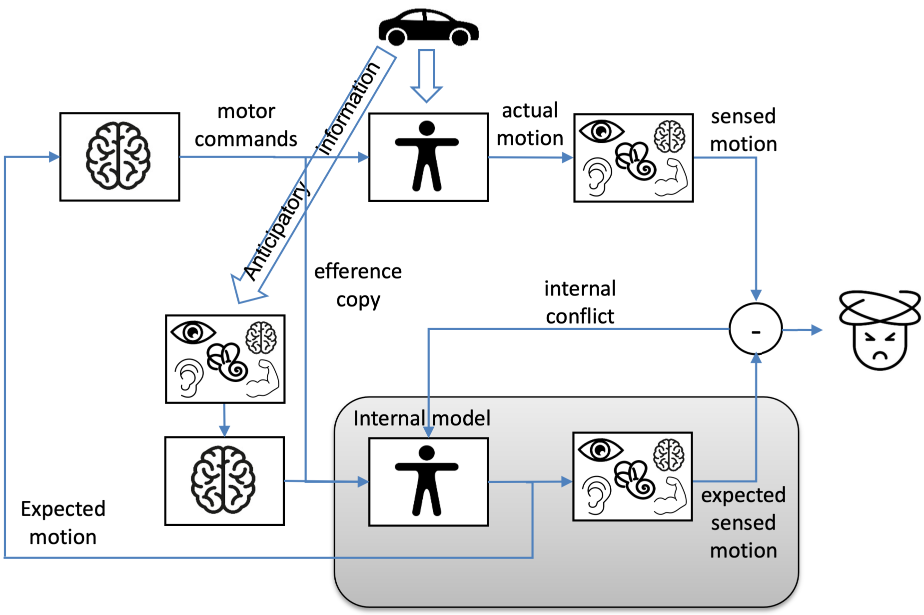


Figure 3-1: Observer Model with Anticipatory Information

For the anticipatory interface to work, it should have a lead time. When looking at the loop, this lead time should be equal to the processing time of the receiving sensory organ, its translation to the internal model, its modeled body reaction, the translation to motor commands, and the actual muscle reaction. Although this is an extremely simplified control loop that only works in the macro system, this model can help to understand what information should be presented at what time to achieve the best and/or fastest results.

3-2 Overview Research by OEMs

Most important players in the automotive industry often do not publish their research. Apart from research done in cooperation with universities, newsrooms of the OEMs are the next best source for the most up-to-date research activities. As this research field is very active, this section will probably be incomplete and outdated once read.

Volkswagen

Volkswagen is researching the mitigation of motion sickness for passengers by means of movable seats and LED strips on the door panel that indicate the car's intentions[1]. The newsroom states that these inventions already have some initial success[1]. These experiments were performed with longitudinal forces, but further plans will also include transverse corners. The experiments were performed in an Audi A4 sedan with various sensors and cameras designed to measure the participant's pulse, skin temperature, and even changes in skin tone[1].

[1] ~~https://newsroom.vw.com/company/the-next-step-in-autonomous-cars-helping-avoid-motion-sickness/~~ accessed: *1-3-2022* → removed but paraphrased in: `https://www.timmonsvw.com/helping-avoid-motion-sickness-the-next-step-in-autonomous-cars/` accessed: *17-02-2022*

Mercedes-Benz Group

The Mercedes-Benz Group has researched on different sources and mitigations of motion sickness in autonomous vehicles. As supportive research, they have performed different simulator experiments, that proved that very different simulators with similar visuals, will give comparable MS reactions (Section 2-5). Their newsroom gives an elaborate explanation on what they are working on[2]. Research has been performed in order to identify the biggest source of motion sickness. Experiments were comparing reading, watching movies, playing video games, or doing a quiz on a tablet. A qualitative evaluation concludes that less cognitively demanding tasks (movie, quiz) are more favorable than tasks that require more concentration [6]. This preference also correlated with less MS symptoms. The analysis of concentration during the experiment yielded contradictory results. The result presented no clear correlation between task performance and motion sickness symptoms, even though participants subjectively felt less able to concentrate on the task.

Furthermore, a decrease in MS has been seen in experiments that compared different backrest positions. Bohrmann and Eng [5] present experiments that compared passenger's preferences of different statically reclined backrest positions (23°, 42°, 62°), while performing different tasks. The experiment tested different types of realistic driving maneuvers, that all resulted in a significant decrease in Motion Sickness Assessment Questionnaire (MSAQ) in the most reclined position. The results have to be taken with caution, as the participants' subjective angle preference was highly dependent on the performed task.

The newest published research by Bohrmann et al. [7] discusses the results of a visual anticipation cue to inform the passenger of the car's intention. Participants have driven around in a vehicle on a test track. During the experiments, participants were in a 38° backrest position while performing reading and gaming tasks. The received visual information from horizontal LED strips around the window that presented speed-dependent moving information in white, which changed to red during deceleration. The experiment reported a reduction in MS and most participants stated the cueing interface to be helpful.

Jaguar Land Rover

The main focus of Jaguar Land rover has been on MS mitigation by optimizing the driving style. The driving style can be adjusted according to the passenger's wellness score, which is obtained by processing data from biometric sensors [3]."*Intelligent software adjusts acceleration, braking and lane positioning to help avoid inducing nausea*"[4]. Furthermore, in academic collaboration, research has been performed in the use of seating directions, bone-conducting vibrations, and a dynamic response model based on a passenger's neck bones by Salter et al. [32][34][33], respectively.

[2] `https://group.mercedes-benz.com/company/magazine/mobility/motion-sickness-kinetosis-product-development.html` accessed: *17-02-2022*

[3] `https://www.jaguarlandrover.com/2018/preventing-motion-sickness` last accessed: *17-02-2022*

[4] `https://media.jaguarlandrover.com/en-us/news/2020/08/jaguar-land-rover-teaches-driverless-cars-how-reduce-motion-sickness` accessed: *13-04-2022*

Ford

Ford's newsroom indicates that the company has been researching MS as early as 2017 without stating a focus on autonomous vehicles[5]. The research is performed with several experts from their research facility in Aachen, as well as TNO and VU Amsterdam in the Netherlands. Initial testing was focused on cabin design, such as the placement of screens to increase the view of the road on both sides around the screen. Schmidt et al. [37] have published the results of an international survey with 4,479 participants with a near equal participant distribution over five different countries, which results were discussed previously in Section 2-2. The newsroom article[5] also mentioned research plans of anticipatory warnings for passengers that are not watching the road. An experiment by Kuiper et al. [26] used verbal audio anticipatory cues to announce forward or backward motion in an enclosed cabin has shown promising results. The control group, which got the same cues at quasi-random moments, had a consistently higher MISC score at the end of the experiment.

BMW

The german manufacturer performed a large-scale experiment (n=583) regarding differences with inner or outer city driving while performing different NDRTs in different seating orientations. The research performed by [36] concluded that on an average ∼26-minute drive, a lot of problems were considered to be insignificant. "*Descriptive analyses showed that only 9% of the n=583 participants felt distinctive symptoms of MS and less than 1% reported nausea.*" Therefore, their conclusion holds that MS should not be a factor to be considered in future vehicle layouts. The advice is to continue research on the effects of NDRTs, as this gave small but significant differences with the baseline.

Volvo

Before the usage as MS mitigation, Volvo has researched sound cues to provide relevant information to the driver. They believe sound to be the most passenger-friendly medium. By panning the radio for the driver to be subjectively identical in loudness, warnings were handled faster and with higher accuracy [15]. Their research planning on MS mitigation was presented in 2019 in Larsson et al. [27], which was mainly focused on sound interfaces and includes the expected challenges. The research by Fagerlönn et al. [16], presented a range of audio cues regarding the vehicle's intentions and perception during inner-city driving. Subjects had increased trust in the vehicle and clearly prefered a vehicle with such an interface.

The experiment that followed had promising results in a reduction of MS with a high user acceptance. The experiment of Maculewicz et al. [28] had discrete sound cues that indicated acceleration, deceleration, left and right maneuvers[6]. The recommendation is to further investigate the use of a sound interface and to verify if it is still successful in a realistic setting that introduces a lot more noise to the passenger, such as other traffic.

[5] `https://media.ford.com/content/fordmedia/feu/de/de/news/2017/04/05/car-sickness-research-to-put-brakes-on-family-road-trip-curse--t.html` accessed: *25-3-2022*
[6] `https://youtu.be/YL-vrYbprjw` accessed 17-02-2023

Others

DLR reported the results of a pedestrian's perception of different light signals on the dashboard in a VR experiment by Wilbrink et al. [42]. The interface presented either perception or intention. The results of a post-experimental survey by DLR were considered to be significantly better in terms of trust and understanding than the baseline, without a clear preference for presentations of perception or intention.

Research on a sound interfaces combined with a wearable galvanic cutaneous stimulation (GCV) device has also been shown to have MS mitigating effects on active drivers [17]. The experiment was conducted in a fixed base simulator. The biggest reduction in head sway was found with the combined interface, while the sound stimulation had the biggest decrease in Motion Sickness.

3-3 Sound Interfaces

By accident, the Rolls-Royce engineers found out that removing all sound from a vehicle, disorientates people[7]. During test drives, it became apparent that this was simply too silent and had to be changed according to the test drivers. This reversely proves that passengers or drivers use the vehicle's sound for orientations to some degree. Unintrusive sound interfaces were designed to alarm drivers by temporarily panning the stereo to have equal sound for the driver's ears, which had positive effects in terms of reaction time and experience [15].

Another experiment by Fagerlönn et al. [16], that presented the perceptions, as well as the intentions of the vehicle by means of a sound interface, increased the trust in the autonomously driving vehicle. A range of different sounds was used to identify different elements as a crossing pedestrian or braking for a traffic light.

Different strategies have been investigated regarding a sound interface. In a very controlled experimental setting, Kuiper et al. [26] has shown MS improvements by verbally stating the intentions of a cart going back and forth. An experiment with higher fidelity used a vehicle on a test track that used different discrete sounds for accelerations, deceleration, a left- and right corner[8]. The experiment by Maculewicz et al. [28] had MS mitigating results with a high level of passenger acceptance.

3-4 Light Interfaces

A HMI using light cues has been researched in several ways. Nearly all research presents results that indicate an improvement in either driving comfort or trust in autonomous driving ([42], [19],[24], [4], [22]). However, as these did not present a significant winning design, more research is necessary to find the most intuitive signal. After this, the next important step would be to standardize it in order to avoid confusion between vehicles from different manufacturers. Most research uses a discrete cue to inform the passenger of an upcoming or

[7] Rolce Royce: `https://edition.cnn.com/2020/09/01/success/rolls-royce-ghost-sedan/index.html` accessed: 19-01-2023

[8] Sound cues: `https://youtu.be/YL-vrYbprjw` accessed 17-02-2023

current maneuver. This does not allow for differentiation between the intensity and time of different maneuvers.

Comfort and trust in autonomous decision-making can be improved by presenting the vehicle's intentions with a light cues on the dashboard. This has been shown in a virtual reality experiment involving a pedestrian crossing by Wilbrink et al. [42]. This interface is similar to the sound interface of [16]. Discrete light signals for left and right presented MS mitigating effects and increased situational awareness [4], However, a comparable setup actually increased the symptoms [22]. As the results are not consistent, it is clear that this type of interface design still needs iteration or changes.

A design with clammed speed dependent on light cues has been tested by Bohrmann et al. [7]. This experiment, conducted on a test track, only tested the response to longitudinal accelerations. As the results had a significant MS mitigating effect, the recommendations were to further investigate lateral accelerations and the learning effect of the interface.

Color

The color of the cue can have an important influence on how the cue is intuitively perceived. This effect has been researched for an external Human Machine Interface [12]. The results clearly agreed with the hypothesis that red means 'stop' and green means 'go', however, they caused some confusion whether this referred to the vehicle or the pedestrians. The same research found that cyan was perceived as a more neutral color.

It has been shown that a significant color change in a peripheral display creates the best sense of awareness for new information [29]. A significant color change can have an even larger effect than a change in intensity. This should be kept in mind when designing a light-based interface.

Handheld

One of the catalysts for MS is reading or performing other NDRT. Therefore, Meschtscherjakov et al. [30] tested an on-screen motion interface, that informed the passengers (n=10) of live movements by moving bubbles on the sides of the screen. The experiment yielded promising results. However, such an interface requires passengers to install software on their personal devices. The interface also had a screen size penalty, as the bubbles have to be presented. This especially has its downside for devices with smaller screens, such as phones.

3-5 Timing

Different experiments use different interfaces, but also different timings. Those timings, are mostly presented without clear reasoning. A lot of different interfaces were tested in completely different experimental settings. While keeping in mind that they are not directly comparable, however Table 3-1 presents a short overview of the most relevant experiments using anticipatory motion cueing.

Table 3-1: Cue Timing of Relevant Experiments

Method	Description	Timing	Source
Sound	L4 mode on track	-2s	Maculewicz et al. [28]
	Closed box lateral movement	-1s	Kuiper et al. [26]
Light	Side LED strip	-2s	Hainich et al. [19]
	Longitudinal speed dependent	+0.02s	Bohrmann et al. [7]
	discrete L/R cues	-3s	Bin Karjanto et al. [4]
		-3s	Karjanto et al. [22]
Movement	driving car; pushing backrest	-3s	
Bone vibration	discrete L/R cues	-1s∼	Salter et al. [34]
On-screen	moving bubbles while driving	0s∼	Meschtscherjakov et al. [30]

3-6 Application Considerations

One of the main goals of a MS mitigating interface is to increase overall passenger comfort. In order to increase overall passenger comfort, it is important to use a design philosophy where the interface has to be designed with not only MS in mind. Apart from vehicle branding and luxury feel, the perceived beauty of a HMI can actually improve its effectiveness and usability. In a touchscreen experiment by [39], participants had improved performance with improved aesthetics. The performance was even higher than with an interface designed for improved usability.

It is also important that the interface fits within a broad range of (future) cars' interior design. Some future concept cars have very different interiors compared to conventional cars. Therefore it is important to design an interface that is not limited to being used in conventional seating orientations.

Trust & Understanding

A passenger's understanding of the vehicle's intentions can also help to understand and trust the autonomous vehicle. Knowing how the vehicle will react when a dangerous scenario is presented can increase trust and therefore comfort. Virtual Reality based research by Wilbrink et al. [42] and Fagerlönn et al. [16], has shown promising results for light and sound HMI-interfaces (respectively) both presenting a vehicle's perceptions or intentions for reaction on a pedestrian crossing. These were both considered to be large improvements in trust and usability compared to the baseline without an interface. For both experiments, there was no clear preference for information on perception or intention.

Chapter 4

Conclusions Literature Study

As can be concluded from the previous chapters; there is no clear or complete or standard solution for the mitigation of MS in autonomously driving vehicles in the public domain yet. This chapter will conclude on the three literature study sub-questions as discussed in Section 1-2.

Current Research

Section 3-2 discusses the different types of anticipatory interfaces that are designed to mitigate MS. The active interfaces that are mostly considered are using light or sound to transfer information. Other methods used moving the backrest and wearables. The experiments conducted vary in fidelity and system completeness, but consistently show a small decrease in motion discomfort. Most results do not have extreme improvements, however, the consistency provides trust in the working and applications of anticipatory interfaces as MS mitigation.

Design Considerations

For the design of the interface and the experiment, it is important to understand all possible influences MS and driving comfort. This should be used to design the interfaces as well as the experiment. The human observer model has been an important source of inspiration in the design of the interface. From this model, it becomes clear that the anticipatory information could be used as input to the *internal model*, which could possibly reduce the *internal conflict* that leads to MS. Passengers should be able to see or learn a clear relation between the information from the interface and the following accelerations. The information should preferably be on a skill-based level, rather than a rules level of cognition. This is because the focus of a passenger, especially during NDRTs, has shown to have a significant effect on MS. Therefore, to avoid varying interface workings, the interface should require minimal focus or cognitive demand. In the design, it is also important to realize that the "beauty" of the interface, plays a role in its acceptance and usage.

Possible Research Contribution

Different types of anticipatory interfaces are rarely compared or combined. Most experimental conditions are significantly different, which makes it difficult to compare the results of different interface types. Such a comparison could help define what type of interface is best suitable for MS mitigation and thus should be further investigated. To ensure the possible use of the interface, the scenario fidelity of the passenger should be as practically applicable as reachable.

The comparison should be complete and should include a MS progression measurement during the full experiment as well as subjective feedback on the full passenger experience. The subjective feedback should include comfort, intuitiveness, intrusiveness, and trust. This can be tested by means of closed Likert based surveys and completed by asking for open feedback comments on relevant elements.

Part III

Concept Design; Preliminary Analysis; and Experimental Setup

(This part has been graded for the AE4020 Course)

Chapter 5

Concept

In order to answer the research question by means of an experiment, specific anticipatory cueing interfaces had to be designed. This design process was done in several phases: Concept, hardware, software, tuning, and preparation for participant testing. This chapter focuses the concept of the interface and how it should ideally be perceived. The hardware and calculations from the actual implementation will be discussed in Chapter 6. Chapter 9 will discuss how the parameters were tuned to best fit the concept description.

5-1 Design Pillars

Some pillars were identified in order to make the concept as relevant as possible. The pillars were chosen such that the concept could lead to a final design that could be optimized and applied to new vehicles. After the literature study and some relevant discussions, some design pillars were chosen. For clarity, the main design effects of each pillar are mentioned.

- **Feasible** - *to be used in a consumer market vehicle*
  - System must be mass-producible, cost-limited; and must be designed to fit a car.
- **Complete/Final solution** - *not designed for the experiment only*
  - The design should not be limited to experimental conditions and should be able to be used in most vehicles, including unconventional seating orientations.
  - Should be compatible with all realistic driving scenarios.
- **Non-intrusive** - *no headphones/handhelds/etc.*
  - The system should not limit a passenger's movements, should be car-fixed and should not give extreme stimuli that may decrease driving comfort.
- **Low cognitive demand** - *information processing does not require concentration*
  - The anticipatory information should be a similar information type that is normally fed into the human's internal model, limiting the need for processing. Therefore the information is chosen to be analog rather than discrete.
- **Intuitive** – *no training required*
  - No complex information is presented, also in line with the previous pillar's decision.

5-2 Conceptual Design

The anticipatory interface presents **analog directional** information directly linked to the vehicle's accelerations with a lead time and "smoothing" filtering. Figure 5-1 represents the concept at the end of a left cornering maneuver, where the vectored cue follows the acceleration vector. There is a direct linear relationship between the anticipatory cue and the upcoming acceleration. Thus passengers should be able to distinguish different maneuvers by noticing a difference in intensity and/or direction of the cue. Equation (5-1) shows the relation between the vehicle's acceleration and cue in pseudo-code before filtering.

$$
\begin{aligned}
Cue_{intensity} &= K \cdot acc_{magnitude} \quad [m/s^2] \\
& \quad if \quad Cue_{int.} \geq Cue_{max} \rightarrow Cue_{max} \\
Cue_{direction} &= \tanh \frac{acc_{sideways}}{|acc_{longitudinal}|} \quad [rad] \\
Cue_{type}: & \quad if \quad acc_{longitudinal} \geq 0 \rightarrow acc.\ cue \\
& \quad if \quad acc_{longitudinal} < 0 \rightarrow dec.\ cue \\
Cue_{back}(int., dir.) &= Cue_{front}(int., \pi - dir.) \\
(mirrored) &
\end{aligned} \tag{5-1}
$$

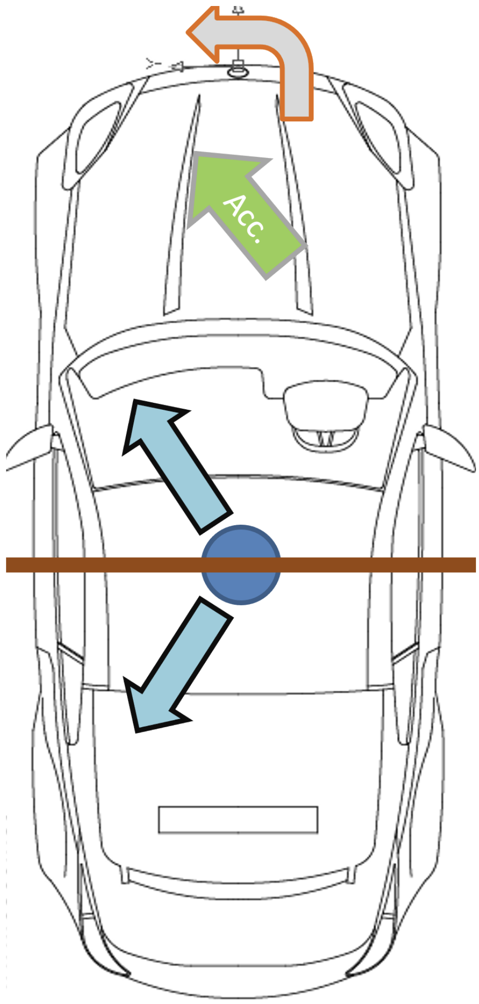


Figure 5-1: Conceptual Representation of an Interface (end of a left corner)

For light cues, it is impossible to represent accelerations in all directions within a static passenger's visual field. Therefore, several cues will be represented in the frontal 180 degrees and change its cue type to an acceleration or deceleration cue. To be visible in all seating orientations, the cue is mirrored from front to back.

5-3 Interface Types

The concept is designed with a light and sound interface in mind. These were chosen as they are the most feasible in terms of added production and are able to represent useful time-bound information with a certain lead time. In the thought process, all information from Chapters 2 and 3 was used, where Figure 3-1 is the leading explanatory visual representation of the workings of an anticipatory interface. From this, the options for interface types that can provide relevant information in a car-fixed reference frame and are non-wearable, are limited. Apart from sound and light, vibration mats would be an option. Most of the literature reports on light and sound interfaces, so these would be the most relevant to compare. Next to this, vibrations mats would be less easily applied into a car-fixed reference frame and are therefore harder to compare to the other interfaces and less robust to moving passengers.

The interface hardware should be able to represent the intensity and direction of the anticipatory cue. Although this study is not focused on the artistic interpretation of a car, it is still important to consider. A study by Tractinsky et al. [39] presents the relevance of beauty in an HMI interface in correlation to its perceived usability. Here, improved interface aesthetics has shown to have a larger effect on perceived usability, compared to an actual practical usability improvement. This was kept in mind during the interface and cue design.

5-3-1 Light Interface

As stated earlier, the cue has to be able to present a direction and an intensity. After considering all previously discussed elements, a 360 degrees individually addressable LED strip has been chosen. The 60LED/m standard, with a blur cover, was considered to be sufficiently smooth and is also already used by VW ID as ambient lighting[1][2]. To ensure that the cue is in the passenger's visual field during NDRT, the strip will be placed at a height just underneath the vehicle's window. The concept ground rules allow a lot of design freedom, which would allow for other even more visible placements, such as above the windows or even combinations of several strips placed on different heights.

5-3-2 Sound Interface

Most vehicles on the market, have good sound systems. The existing sound system could be used as a surround sound interface. Vehicles are usually filled with sound-isolating materials, like textile roofs, doors, and chairs. Therefore, a functioning surround sound can be considered. Since the used simulator did not share this characteristic, this could not be considered in the experiment (see Chapter 10), as it affects the directional sound perception. Therefore, the sound interface can not be tested without the directional light information in order to test the concept. Thus this results in a combined light and sound interface to be compared to the light interface.

5-4 Cue Types

To ensure correct experimental results, it is important to make sure the participants can clearly distinguish the anticipatory cues from all other external inputs. Therefore, the cues were designed to seem artificial rather than natural. As earlier discussed, acceleration and deceleration have separate cues. This section will only discuss the final design that has been used in the main experiment. Apart from many small iterations, some main parameters have been tuned by means of test trials as discussed in Chapter 9.

[1] `https://www.youtube.com/watch?v=5UvwtQ50BdA` last accessed 14-12-2022

[2] https://www.volkswagen-newsroom.com/en/stories/hello-id-light-how-the-new-id-models-communicate-with-the-vehicle-occupants-via-a-light-strip-6963 last accessed 17-12-2022

5-4-1 Cues to Avoid in Cars

Like any other HMI interface, these interface cues should avoid ambiguity or a bad combination with other interfaces. Therefore, some sounds and lights are to be avoided. In order to adhere to the "final solution" pillar, it is important to think about a vehicle's full operation rather than just the MS mitigation interface. Confusing cues that may be linked with other information, like warnings should be avoided. Warnings are usually designed to have annoying loud sound beeps and/or alarming colors like red or orange. Apart from avoiding a startled/surprised reaction, it is important that the passenger will still be alarmed by given warnings while using the interface. This means that there should be enough contrast with such alarms. The interface could possibly turn off the cues in the case of an alarm to ensure they will not be overshadowed. For the same reason, it is important to avoid sudden flashes or color changes for normal operation. However, this should not be a problem for abnormal changes in acceleration, as this should actually warn the passenger.

The Vehicle's Environment

For other traffic, the interfaces may not go unnoticed. Therefore it is important to avoid cues that could potentially create confusion that could lead to dangerous scenarios. A survey by Dey et al. [12] (N=400) was conducted to understand what messages a vehicle-pedestrian HMI should use or avoid. This concluded that animations were confusing and that red and green are intuitively associated with 'stop' and 'go'. However, this was true for both the vehicle's intention as well as pedestrian instructions. Therefore, this can lead to confusion, thus green should also be avoided. Furthermore, all sounds that may sound like honking and alarming should be avoided for safety reasons. And in addition, for commercial applications, the branding and luxury feeling of the lights and sound should be considered.

5-4-2 Light Cues

The light cue is presented on a LED-strip mounted under the windows all around the car. In the peripheral visual field, subjects will have the best reaction to significant color changes [29]. The light has two colors that change according to the direction of the acceleration as described by Equation (5-1):

- Acceleration: [20 190 75 5] RGBW
- Deceleration: [254 0 140 0] RGBW

The neutral cyan was chosen for acceleration in order to avoid correlations with existing information. The violet deceleration color is a bit red-tinted as this would not create any problems and is already associated with braking. Both colors were chosen performing tests. The acceleration magnitude is translated into light brightness and pixel width of the cue as brightness alone did not present the intensity fluctuations clearly enough. Section 6-2 discusses the exact relations. The subjective intensity is increased by making the cue brighter as well as wider.

Direction

The cue direction had to be designed in a way for the passenger to always see and interpret the direction unambiguously correct. Therefore, multiple light points are strategically chosen to ensure this. The final design that complies with the goal of the concept was found after many small iterations. In Figure 5-2, the positions of the light cue, in a purely longitudinal acceleration, are presented together with the angle deviation maxima of one of the cues. One of the light cues was positioned right in front of the passenger, as this felt natural.

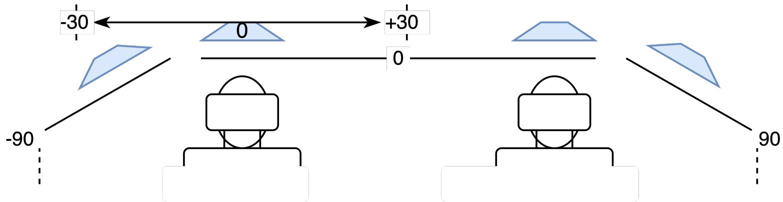
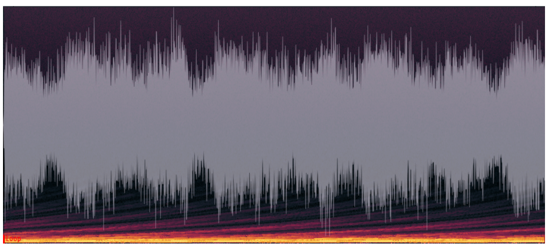


Figure 5-2: Frontal View of Cue Locations (numbers in degrees)

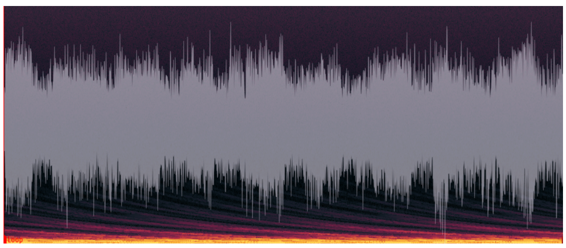
Each corner has two cues is to increase visibility without increasing light influx. Only when the vehicle has purely sideways accelerations, a cue will be in the front. Together with the light of lack of it on one of the sides, the passenger can identify the direction. This allows passengers to identify sideways accelerations at any given time. If the cues would be equally divided, the passenger would only be able to identify the direction when the direction is changing and not when during a stable sideways acceleration.

5-4-3 Combined Light and Sound Cues

The light interface will be compared with a combined interface. Hereby, the sound will be an addition to the light interface, thus this section will focus on the sound alone. The sound has been designed to be artificial, intuitive, and give an illusion of acceleration or deceleration. In most cars, there is some relation between a rising frequency and forward acceleration and vice versa. The cues have been made by a synthesizer with this idea in mind. The Shephard's tone illusion gives the illusion of a changing frequency while staying close to constant [38]. This allows for little change in characteristics for long cues and is therefore optimal for experimental conditions, as it creates less difference between cues than sounds with actual changing frequencies would.



(a) Acceleration Cue (rising Shepard's tone)



(b) Deceleration Cue (falling Shepard's tone)

Figure 5-3: Spectograms of Cue Sounds (15s)

The direction of the sound was kept more simple and follows Equation (5-1) more directly, with only one cue (and a second mirrored cue). With a purely longitudinal acceleration, the cue will come from the front. With a normal speaker placement, this means the sound will be equal from each corner of the vehicle, as it is also mirrored to the back speakers. In Figure 5-4 the location of the front speakers and three examples of speaker volume levels. Hereby, 1 is referring to the full volume as input from the intensity. Between these conditions, the individual volumes are gradually changed.

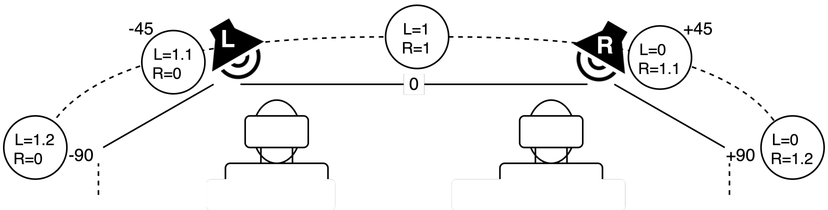


Figure 5-4: Frontal View of Cue Locations with Three Examples (numbers in degrees)

As the cue is mirrored to the back, such a cue should have an equal subjective sound speaker volume. For purely sideways accelerations, the cue will only be played on the speakers of the inside of the corner. This effect was, however, overshadowed by the echoing in the experiment's simulator composite-based hard shell, making it hard to identify cue direction. Therefore, in order to correctly identify the direction, the sound interface has to be combined with the light interface.

Filtering

As mentioned earlier, sudden changes and flashes should be avoided for normal operation. Since acceleration can change rather quickly in some maneuvers, it is necessary to add some form of filtering to the intensity and direction of the cue. The exact calculations will be presented in Section 6-2.

Chapter 6

Simulator Setup

A large part of the work in this project was about the systems preparations in the research simulator. All hardware and software were made in-house as an addition to the existing SIMONA Research Simulator (SRS) interfaces. This chapter will describe the final system, for both the hardware and the software. Both are designed to approach the concept as described in the previous chapter. During the implementation process, some iterations were made to converge to the best practical implementation of the concept. These findings will be discussed in Chapter 10.

6-1 SIMONA Research Simulator

The SRS[1] is designed for research, which makes it very different from other most simulators. The simulator is designed and assembled in-house in a designated building next to the Aerospace Engineering Faculty at the Delft University of Technology. The faculty developed the Delft University Environment for Communication and Activation (DUECA)[2] real-time calculation software as a backbone for several research platforms within the Control & Simulation section. This middleware layer is able to connect a wide range of different devices such as the motion system and the simulator visual but is written to be easily adjustable. The simulator has a $180° \times 40°$ collimated outside visual screen.

Motion

It uses six hydraulic pistons with a total stroke length of 1.25m each. For this experiment, all motions and positions are generated offline and will be identically performed with high accuracy during each experiment trial. The experimental setup is limited to the motion space this can produce. Since the simulator's motion space is limited, some accelerations

[1] Facilities website: `https://cs.lr.tudelft.nl/simona/`
[2] DUECA open source repository: `https://github.com/dueca/dueca`

have to be partially cues with tilt motions as acceleration illusion. The experiment's motion profile consists of 3 types of maneuvers as explained in Section 7-4. Due to limited motion space, these motions can not be fully represented. How this is compensated, will be further elaborated on in Section 9-1. This report will not go into the specifics of the motion of the platform, as this is documented by the faculty.

Basic Simulator Layout

The general setup of the experiment can most clearly be visualized in a picture of the actual simulator. Figure 6-1 shows the simulator layout during the experiment in a panoramic view. The subject takes place in the left-hand seat of the simulator.

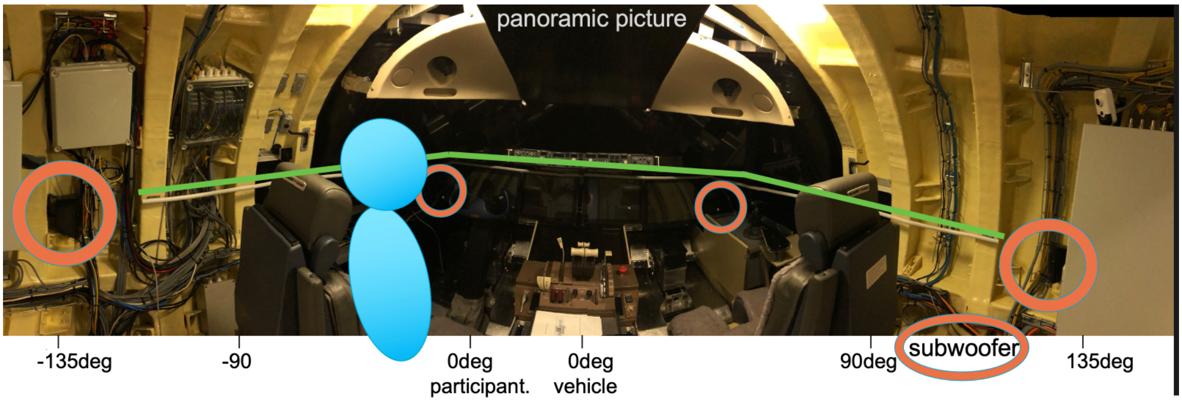


Figure 6-1: Panoramic Picture of Hardware setup

The participants are in a pilot seat with a Boeing 777 steering column in front of them. All (touch)screens are deactivated except for one screen on the right-hand side. This screen is used to present the MIsery SCale as presented in Appendix D. Furthermore, the cabin lights are switched off and the outside view will present a static horizon. The chair is able to move up and down to make sure each participant has the correct inner ear placement, for the acceleration illusions using tilt, to be correct.

6-2 Cue Code

All calculations are done offline as the trial's motion is identical for each individual trial. The cues have a direct linear relationship with the planned accelerations of the route that is described in Chapter 7, before the simulator's motion filter with acceleration illusions is applied. In order to make sure the used values are in line with the concept, they are tuned by means of a tuning test trial as described in Chapter 9.

It is chosen not to consider the extremes of the acceleration magnitude. This makes the cue intensity linear to the trimmed acceleration magnitude as can be seen on the next page in pseudo-code. The lower bound trim would be relevant is a real application with small unexpected vibrations, however, this will not be noticeable in this experimental setting.

A maximum magnitude is linked to a chosen acceleration to avoid extreme sound or light cues.

$$\begin{aligned} & accel_{trimmed} = |acceleration| \\ if\ |acceleration| > accel_{cue\_max} \rightarrow \quad & accel_{trimmed} = \quad acc_{cue\_max} \\ if\ |acceleration| < accel_{cue\_min} \rightarrow \quad & accel_{trimmed} = \quad 0 \\ & \text{Cue}_{magnitude} = \frac{|accel_{trimmed}|}{accel_{max}} \end{aligned} \tag{6-1}$$

$$\text{Cue}_{direction} = \text{atan2}\left(\frac{\partial\, acceleration}{\partial\, lateral}, \frac{\partial\, acceleration}{\partial\, longitudinal}\right) \tag{6-2}$$

The magnitudes and directions following these equations have fast fluctuations that can feel sudden or startling. Therefore, some form of filtering has to be applied to avoid this. The specific filtering should be investigated in further research, but it has been chosen to use lead and lag, by applying a central moving average for each data point. The lead and lag are identical as the Matlab command *movmean* was used in the following way.

$$\begin{aligned} \text{Cue}_{magnitude} &= \text{movmean}(cue_{magnitude}, k_m) \\ \text{Cue}_{direction} &= \text{movmean}(cue_{direction}, k_d) \end{aligned} \tag{6-3}$$

In order to make sure the correct k_m and k_d values were chosen, different values have been tested as described in Chapter 9.

Sound Interface

For sound to follow the concept, it should be designed such that the passenger can distinguish between different directions. The SRS has a 5.1 Dolby speaker system, that will be used for this experiment. The speakers are individually controlled to ensure correct sound placement. For longitudinal accelerations, all speakers will be subjectively equally loud. For the simulator, the rear speakers are 10% louder than the front. When the direction rotates away from the center, the opposite side speaker will be linearly faded out between 0 and |30| degrees. On the other hand, the side of the cue direction will linearly get 20% louder between 0 and |90| degrees. This creates extra contrast between lateral and longitudinal accelerations.

Light Interface

Apart from all software, the hardware for the LED strip had to be made for this experiment. The Light interface is designed and built specifically for this project while ensuring modular usage freedom for possible future projects. The concept requires an all-time visual 360 degrees, for all seating orientations. For practical reasons, this experimental setup is built to have a ∼270 degree visual. The participants are placed facing the front and will therefore not notice a significant difference. An individually addressable SK6812 RGBW strip was used with a blur strip and 60LED/m resolution (similar to [7] and Volkswagens ID). The LED strip is controlled via a Teensy 4.1 Arduino-based microcontroller, which is connected to the simulator software over the USB. The *FastLED.h* and *FastLED_RGBW.h* libraries are used to control the data output to the SK6812 LED chips. All code was saved on version-controlled repositories.

The intensity is represented with linear changes in brightness and width. The brightness is changed by scaling the RGBW codes (Section 5-4). As discussed, the width also changes linearly with the magnitude. The range has been tuned (Chapter 9) and its range is represented below:

$$\begin{aligned} &\text{for } Cue_{magnitude} : \text{[0,1]} \\ \text{RGWB}_{actual} &= \text{RGBW}_{color} * Cue_{magnitude} \end{aligned} \tag{6-4}$$

$$\begin{aligned} &\text{for } \#_{pixels}\text{: [3-40 pixels]} \approx \text{[5-67cm]} \\ \#_{pixels} &= \#_{min=3} + \#_{scalefactor} * Cue_{magnitude} \end{aligned} \tag{6-5}$$

As shown in Figure 5-2, the cue is split into different light sources. After the acceleration is translated to intensity and direction, the cue is split into different light sources. All eight light sources (two in each corner) react identically to changes in direction or intensity. The location is chosen such that the sources closest to the 0 deg, are positioned right in front of both front passengers. The other light sources are placed on the side at an equal distance from the corner. The angles used are described below:

$$\begin{aligned} &\text{for } Cue_{direction} : [-90deg, +90deg] \\ LightCue_{direction_{source\,1-4}} &= \frac{dir}{3} \pm 35deg \pm 11.5deg \end{aligned} \tag{6-6}$$

For the source to be decreasing subjectively linear to the edges of the cue, the sides should be exponentially lowered in brightness as can been seen in Figure 6-2 below. This is done using the following equation and is tuned subjectively by the researcher to look like a natural fade. The formula uses distance rather than a ratio. The reason this works is that the initial RGBW_{actual} value increases together with the width increase.

$$\begin{aligned} f(x) &= 0.85^{10x} * \text{RGBW}_{actual} \\ 1pxl/x &\approx 1.6cm/x \end{aligned} \tag{6-7}$$

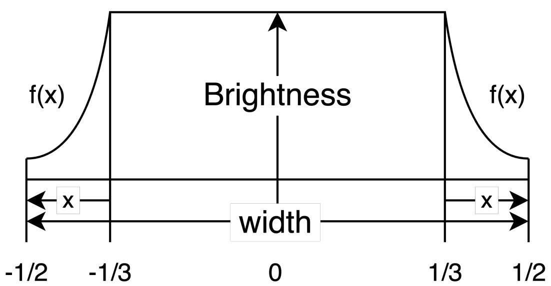


Figure 6-2: Brightness-Width relation for each Light Cue Source

6-3 Electric System

The electrical system is designed to be robust for the maximum use case. The power supply, cables, and connectors are designed to perform optimally under maximum load/brightness. The color of the SK6812 RGBW LED chips could fade if the voltage on the strip becomes too low. The maximum distance between a chip and a power cable is 1m strip or 60 chips to ensure a high enough voltage. The LEDs can draw 0.25 $Watt$ each on full power. To cover the full 5 $meter$ strip of $60LED/m$, a 5 $Volt$ - 18 $Ampere$ supply is used. The cable tree is installed in the simulator and can be connect to each element by hand. The strip is built up of a 2x3 modular strip and can also be used in smaller configurations for later experiments. The power supply is connected to a fused relay on a DIN rail in the simulator that can be controlled from the control room.

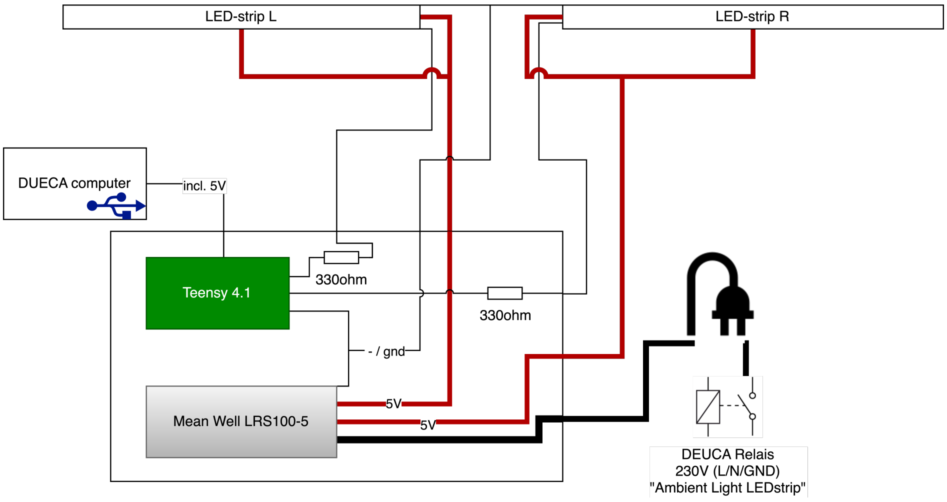


Figure 6-3: Electric Connection Diagram SK6812 LED-strip

The full electric system is presented in Figure 6-3. It can be seen that the microchip is powered separately over USB. Thus the strip power supply can always be overruled without changing communication with the microcontroller. The microchip and the power supply must have the same ground for the signal to be stable. A 300Ω resistor is added between the controller and the strip to mitigate any spikes, as adopted from community-based common practice.

Chapter 7

Experimental Conditions and Considerations

This chapter will discuss the considerations that were made in the design of the experimental conditions that will be described in Chapter 8. This chapter also focuses on the simulator's motion, which has relevant effects on the MS and linearly the interface's behavior. The experiment will test the effectiveness of a light interface and of a combined light and sound interface.

7-1 Information Management & Order Biases

Literature on similar experiments does not show a clear consistency in their experimental setup. Salter et al. [32] avoid order biases by performing a between-participant experiment, which may create biases from individual differences. In the experiment of Cheung and Vaitkus [11] participants have seven minutes, to get familiar with the interface, however, this may affect the results afterward. Especially if the cue is presented without movements, this may lead to incorrect learning which could even create negative effects. Hainich et al. [19] takes this one step further by fully explaining the underlying ideas of the interface, which excludes the option of testing the interface's intuitiveness. A single trial experiment with a light cue interface by Bohrmann et al. [7] does not inform participants of anticipatory LED interface at all. Considering the results this experiment wants to obtain, none of these options work.

Order Effects

As mentioned, at least three trials are necessary to answer the research question. However, since these are human trials, there will be order effects. The best way to account for possible order effects is to test all different orders to see the differences. Three trials can be performed in six different orders, thus this experiment needs a multiple of six participants. Although more is always statistically better, for practical reasons, this experiment will use 18 (3x6) participants. For a fair comparison, it should be a goal to have subjects as informed during their last trial as during their first trial. This is the assumption that is made when comparing subjects that had different orders. The post-trial surveys should therefore not be more informative than the briefing, as this would affect the second (and third) trial.

Obtaining Correct Results

Before designing the experimental conditions, it is important to think about the data that the experiment should output. The main output should be the effectiveness of the interfaces compared. This results in three experiment trials, as the effectiveness of it can only be evaluated with a baseline trial. During the trials, it is important to measure the amount of experienced motion sickness, which can be done using the MISC rating. As motion sickness is described as a broad range of symptoms, the symptoms will be asked by a survey to check for possible unexpected correlations.

Briefing

Information management is a very important part of experiments involving humans, especially since the interfaces will be tested on intuitiveness. Therefore, subjects can not be told about the workings of the interface or how it should be interpreted. It is likely that subjects will find the second trial with an interface more intuitive, as they have experienced something similar. Although some parts of information management in a within-subject experiment are unavoidable, information consistency within the different trial orders should be the goal. This is especially important when filling in the post-trial survey, as different information might result in different answers. Therefore, subjects should be briefed about the three types of trials beforehand.

Surveys

The interfaces are also tested on subjective factors such as trust, comfort, intuitiveness, and intrusiveness. This is not something that is objectively measurable, subjects have to be asked for this feedback. For consistency, this is done by filling out a survey with relevant questions. Most questions are in a Likert style and each closed question should have a counter-question to check for answering consistency. The questions are split up into three categories: motion; interface; and trial comparison. The questions will be discussed in Section 8-3-4 and Table 8-1 summarizes each survey question in keywords.

7-2 Reading Task

A good way to test the concept is to see if it reduces MS-symptoms in one of the most problematic scenarios. Many people suffer from MS while reading in a car. According to a cross-demographic survey by Schmidt et al. [37] (n=1,892), 67.1% of passengers are *likely* or *very likely* to get motion sick while reading. Reading is considered an unpleasant NDRT, as it requires more attention than other tasks [6]. When subjects are not given a NDRT, they are likely to purely focus on the interface. One of the goals of this anticipatory interface is to be able to focus on something else while still being aware of the next move. Thus to put this to the test, subjects will be asked to read a newspaper from a 10-inch LCD tablet. Subjects will be able to choose their own articles which will increase the chances of the them being interested in the reading task. In addition, active decision making is required while choosing a new article, which promotes different types of brain activity. These changes in focus and freedom of choice should better represent the amount of concentration that would realistically occur while driving.

7-3 Visual

For this experiment, it was chosen not to focus on the visual of the drive. Although this decreases the fidelity of the experiment, it also reduces the chance of visually induced biases. Participants will be asked to read on the tablet, and thus will have their faces down. Therefore they would not see many direct movements. On the simulator screen, a static horizon is presented as can be seen in Figure 7-1. The blue sky, white horizon, and gray ground have been chosen to provide a neutral horizon representation. Furthermore, the simulator's cabin lights will be switched off, which will result in an evening-like drive. This is done to reduce focus on the rest of the cockpit and increase focus for the light interface.

Figure 7-1: Outside Visual

7-4 Simulator Motions

In order to create relevant output, subjects should be placed in a driving condition that can be improved by the use of the described interface concept. This means that the conditions should not be designed to have minimal Motion Sickness. In addition, to test the correct understanding of the interface, the motion should not be too repetitive. When the motions, and thus the cues, are too repetitive, subjects could possibly correlate the cue as an event before a movement rather than a linear relation to the accelerations. All three trials will use identical routes and motions, under the assumption that participants will not remember the order of the movements of the previous trial(s).

From the result analysis, the amount of different maneuvers should be limited, but should also be different enough to represent the different representations of the interface's intensity and direction. It should thus also not be a given certainty that every maneuver is a cornering maneuver. Therefore, the following five maneuvers have been chosen:

- Stop and Go
- Defensive corner (L&R)
- Aggressive corner (L&R)

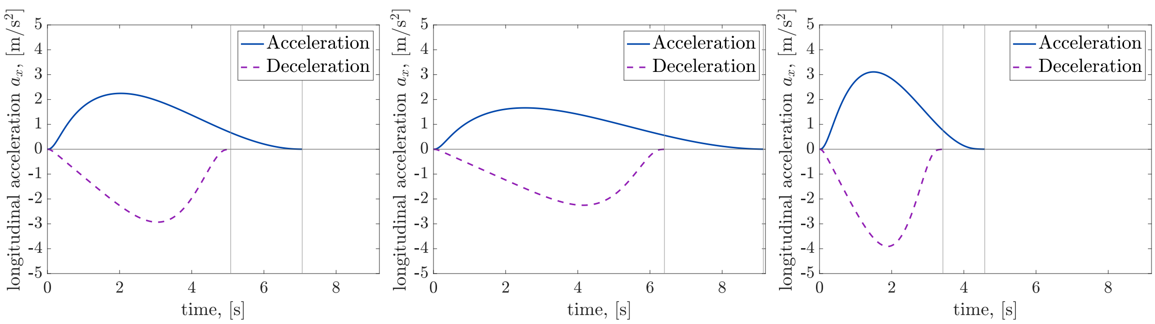
7-4-1 Acceleration Profiles

The route consists of five different maneuvers, as the corners will also be mirrored in the lateral direction. The focus of the design is on acceleration and jerk, as there is no way to distinguish different velocities with a static visual. As a starting point, the minima and maxima of the accelerations that are chosen, are based on the results of Bin Karjanto et al. [4] and Bae et al. [2] and can be seen in Table 7-1.

Table 7-1: Acceleration Maneuvers Maxima (Bin Karjanto et al. [4] Bae et al. [2])

Maneuver	Stop and Go	Defensive Corner	Aggressive Corner
deceleration max g	-0.3	-0.23	-0.4
acceleration max g	0.23	0.17	0.32
side acceleration max g	-	0.3	0.45
side jerk max $[m/s^3]$	-	0.45	2

The longitudinal acceleration and deceleration profiles were based on the kinematic polynomial acceleration model of Akcelik and Biggs [1] in order to create smooth profiles close to reality. The longitudinal jerk values are resulting from these profiles. The free parameter n in the model is equal to 1.0. The free parameter m was chosen per type by placing the acceleration maxima. The 'stop and go' maneuver has this point at 2.0s of the acceleration profile and 60% of deceleration profile. The defensive profile has these acceleration maxima at 2.5s and 65%, while the aggressive profile has these peaks at 1.5s and 55%. The longitudinal acceleration profiles of the 3 different movement types, can be seen below:



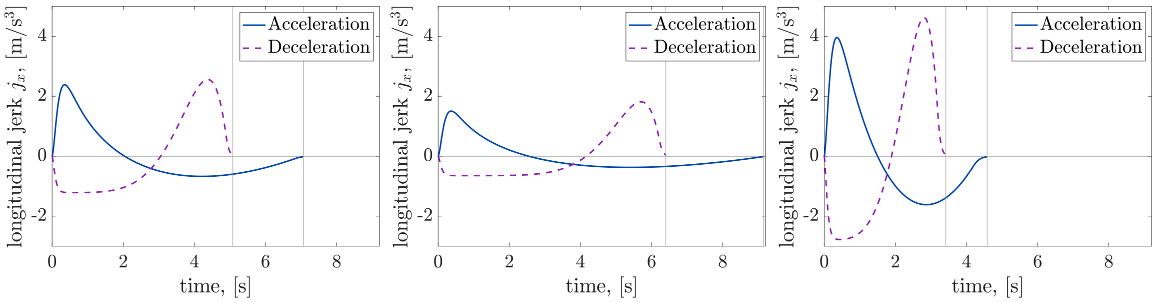
(a) Stop and Go **(b)** Defensive Maneuver **(c)** Aggressive Maneuver

Figure 7-2: Longitudinal Acceleration Profiles Different Maneuvers (different x-axis)

In the design of the profiles, large jerk spikes were actively avoided. In order to achieve this, a second-order low pass filter has been applied to the created acceleration profiles. The equation below is applied to the longitudinal accelerations.

$$H_{acc}(s) = \frac{1}{(\tau_s s + 1)^2} \tag{7-1}$$

The acceleration phase has a time constant of $\tau_s = 0.1$s, while the deceleration has a time constant applied of $\tau_s = 0.05$s. Figure 7-3 presents the resulting jerk profiles of all three maneuvers. In the translation to the simulator motion, an extra filter is applied to further reduce this as described in Appendix B.

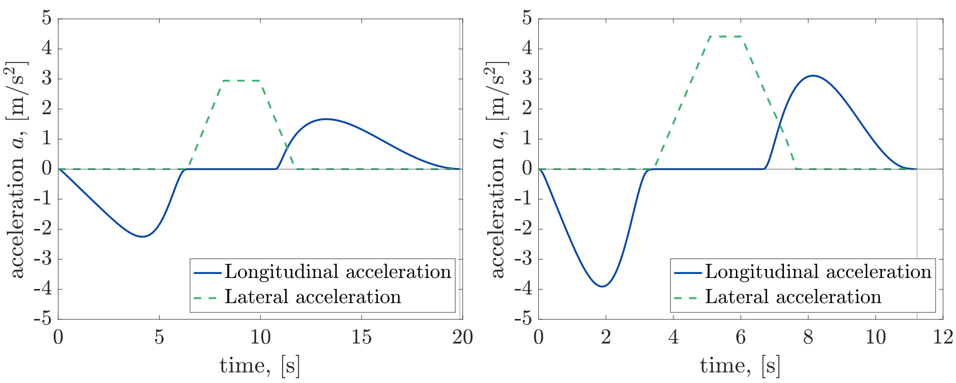


(a) Stop and Go **(b)** Defensive Maneuver **(c)** Aggressive Maneuver

Figure 7-3: Longitudinal Jerk Profiles Different Maneuvers (different y-axes)

The lateral acceleration of the corners increases and decreases with a constant jerk value. As there are no visual conditions, accelerations are more abstract than in a normal scenario. However, the maneuver is designed to slow down before a corner, followed by a clothoid between the straight path and a constant radius corner. This clothoid results in the constant acceleration increase (and decrease) and can be seen in Figure 7-4.

In order to approach a more natural movement, the acceleration phase of the corners starts before the end of the lateral movement. Therefore, the end of the cornering maneuver does not have a constant jerk, as the speed increases. This also has an important effect on the anticipatory cue, as this will lead to more gradual changes in the direction as the acceleration will actually have a combined longitudinal and lateral component in the second transition.



(a) Defensive Maneuver **(b)** Aggressive Maneuver

Figure 7-4: Full Acceleration Profile of Corner Maneuvers

7-4-2 Full Route

The total route that subjects will take each trial is decided to take 30 minutes. This should be long enough to induce MS in susceptible participants without making it too extreme. The order of the maneuvers is designed to be unpredictable, such that the participants can not anticipate on the maneuvers without the use of the interface. The speed of the route becomes an abstract concept as the participant will not get any visual information. Therefore, the entire route is purely designed around the accelerations. There will be an equal number of maneuver types and within the corners an equal number of left and right. Therefore, the total number of maneuvers has to be divisible by six. Between each subsequent maneuver, there will be a ‘straight’ part in which the motion system as has time to preposition. Another route requirement is the coincidence of the MISC rating check with a straight part. This ensures that the scenario of measurement is as similar as possible and reduces overstimulating the subjects. With these requirements in mind, each straight part of the road have semi-random periods between the accelerations. Figure 7-5 presents the route with 60 maneuvers as has been chosen during the tuning as described in Section 9-1.

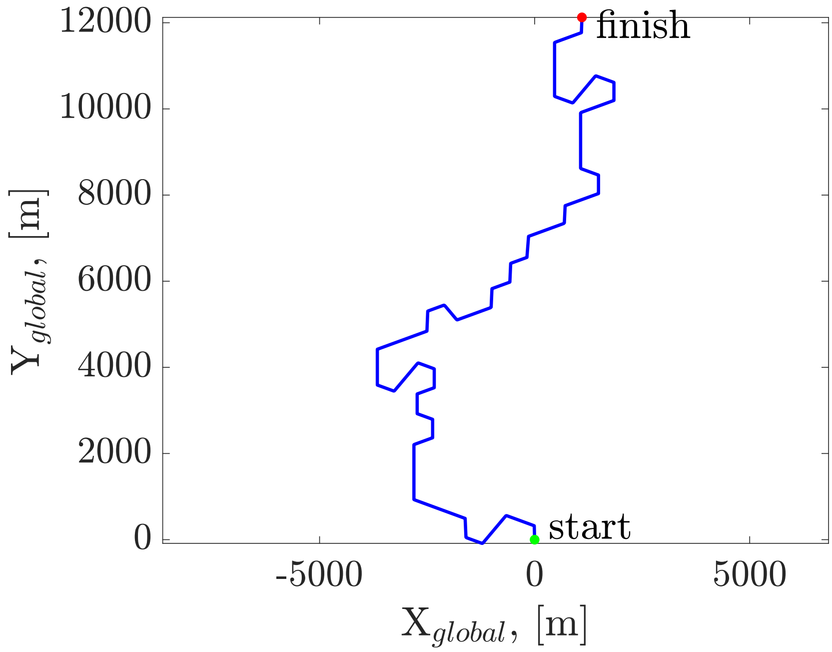


Figure 7-5: Total Route Containing 60 Maneuvers

Chapter 8

Methodology

Experiment in Keywords: *SIMONA Research Simulator - three trials - anticipatory cue - analog vectored cue - cues linear to acceleration - acceleration threshold - control - light cue & sound cue - 18 participants - reading task - tablet - head movement - MISC*

In order to answer the research questions, a within-subject experiment will be conducted with three different trials: Baseline; Light cue interface; Light- and Sound cue interface. All three trials have near identical conditions, as the anticipatory interface is the only actively changing variable. Participants are told that they should act as if they are a passenger of an autonomous vehicle driving home from work while reading a newspaper on a tablet to simulate a realistic scenario in which passengers would experience motion sickness.

8-1 Subject Selection

The 18 participants have been gathered through university networking and flyers. Interested candidates could follow a link to an online survey on qualtrics (Appendix E) that presented relevant experiment information and gathered the following information:

- Motion Sickness Susceptibility Questionnaire (MSSQ)-short
- Motion Susceptibility self-rating: 0-3
- Age / Gender (M/F/X) / Contact information for trial planning

The subjects are chosen from all applicants of the survey. The MSSQ-short has not been a very reliable motion sickness predictor in earlier experiments in the research group by Wijlens et al. [41], however, it is a good tool to avoid outliers.

For the experiment, nine male and nine female subjects are to be chosen in an average MSSQ-short population percentile. In order to select the most suitable subject to fit the data set, a *python program* was written. This program is designed to present the most suitable subject based on the output of the survey while presenting the details of all earlier contacted and/or planned subjects. This allows for fast selection and decreases the chance of an unbalanced subject set or general selection errors.

8-2 Measured Output

The following data are gathered during and after the trial:

- **MISC rating** - Participants will be asked to verbally rate their state on the MISC (presented on the screen in front of them) every minute. This frequency is doubled for 0-5min of the trial and the 5min recovery period after the motion.
- **Head Movements** - An IMU will be placed on the forehead with a headband, to record the free acceleration of the subject's head.
- **After trial survey:** (Appendix F)
  - **Motion sickness symptoms:** - Symptoms experienced during the motion exposure or recovery period were checked through the use of a dedicated motion sickness symptom checklist, including 24 commonly experienced symptoms, at the end of both experiment sessions. Symptom severity was rated on a 4-point ordinal scale.
  - **Trial Questionnaire** - Questions on driving style, comfort, trust, intrusiveness, etc. of the interface. The baseline trial lacks questions about an interface.
  - **Trial Comparison** - After the third trial, subjects will be asked to compare the trials on some key characteristics.
  - **Comments** - For each question category, subjects are given the opportunity to give additional comments about their experience.
- Web-archive of the reading task: New York Times home page (for headlines)

8-3 Procedure

Information management is a very important factor in human trials. Therefore, detailed procedures were prepared, to be as consistent as possible. The given information by email, paper, or verbal communication, is aimed to be as identical as possible for each subject.

8-3-1 Contact

After selection based on the survey, subjects receive an email with the **Experiment Briefing** and the question to reply with their availability. If they reply to this email, they receive **three planned dates and times**, the **informed consent form** (in line with the ethics procedure), and the briefing again. The email also gives information about the location, expectations, preparations, cancellation, SRS safety instructions, and COVID-19 regulations. As preparation, subjects are strongly discouraged to use alcohol or other drugs in the 24 hours before the trial. They are also asked to eat before the trial and be well-rested. All standard email correspondence can be seen in Appendix C.

8-3-2 Briefing

Subjects can prepare by reading the briefing and watching the SRS safety video. If they did not do so, this will be the start of the briefing, followed by the verbal briefing, which can both be found in Appendix C. They are informed of the planning for all trials and about the type of questions they can expect in each survey. This should limit differences in Thereby, subjects are only informed that the three trials will be testing:

- Baseline
- Light interface
- Light & Sound interface

This distinguishment is made without further explanation and will be repeated before the start of the trial. This should improve the awareness of the interface and aims to decrease the search for other inputs. Subjects are told that they will simulate a passenger in a self-driving vehicle, driving to a set destination, while reading a newspaper on a tablet. They are informed to verbally state their MISC rating when they hear a “ping” sound and that the researcher will be silent during the full 30-minute trial unless they have questions or remarks. It is made clear that the goal is not to get very nauseous, and that this will not produce valuable data, thus that they should request to spot when they feel nauseous. It will also be emphasized that they will receive a €10,- Bol.com voucher per trial for active participation, also if they want to stop prematurely for any reason. After the briefing, participants are asked to sign the *informed consent* agreement, if they want to proceed with the experiment.

8-3-3 Experiment

Subjects will be placed in the simulator with the IMU with a headband on their forehead with the 10-inch LCD tablet, which has a 60% brightness. The chair is adjusted to the correct height around which the tilt of the acceleration illusions is designed. They are verbally informed of all the startup procedures and reminded of the trial they are doing. Before the start, they will be reminded to keep their head in a straightforward direction to calibrate the IMU with the first data point. During the experiment, the verbal MISC rating will be written down by the researcher, as well as any comments or relevant details. The data sheet used can be seen in Appendix D. Subjects may request to stop at any time, however, the researcher will also execute according to reason or according to the following logic:

```
Check for each verbal rating:
if MISC ≥ 7 OR #(MISC==6) == 3 then    ▷ total of times 6 has been stated this trial
    Trial ← Terminated
else if #(MISC == 6) == 2 then
    Subject is asked how they feel and given the choice to stop
    Ensure: “Do you want to continue?”
    if “No” then
        Trial ← Terminated
    else if “Yes” then
        Continue
    end if
end if
```

After the 30-minute drive, participants are asked to remain seated for five extra minutes and verbally rate their MISC every 30 seconds, which should be enough to capture most of the recovery. After this, subjects will proceed to a computer to fill in the post-trial survey. If necessary, subjects are allowed to take time to recover from any experienced MS-symptoms before the survey.

8-3-4 Post Experiment Survey

After each trial, subjects will answer a survey to quantify their subjective experiences during the trial. The survey starts with questions on their MS symptoms. The survey questions are split up into several categories. At the beginning of the survey, subjects will receive their €10,- voucher. There will be no questions about an interface for the baseline trial and the trial comparison will only be presented after the subject has completed all three trials. Table 8-1 below summarizes each survey question in keywords, while the full version can be found in Appendix F.

Table 8-1: Post-Trial Survey Questions in Keywords

Motion (each trial)	**Interface** (if interface)	**Trial Comparison** (after last trial)
symptoms	clearness	preferred trial?
comfort	comfort	most extreme trial?
reading focus	motion/cue relation	least comfortable trial?
realistic drive	trust/correctness	use in current car?
verbal MISC distraction	intuitiveness	which trials had identical motion?
body response to movement	intrusiveness	ride with or without interface?
driving style	correct timing	interface improved comfort?
		light vs. combined?

The questions are randomized per category and closed questions have counterpart questions to check for answering consistency. Each category has an optional comment option to elaborate on their answers. The researcher will be present to answer any questions that may come up.

8-4 Ethics

All experiments that involve human trials, have to be checked by the Human Research Ethics Committee (HREC). This committee reviews all human experiments at the Delft University of Technology. Things that are checked are mainly focused on the privacy and safety of the participants and if everything is in line with the TU Delft Code of Conduct. All simulator operations, apart from the added hardware, were previously approved, thus the check was mainly focused on data handling and privacy. Before approval, the data management plan was checked by a TU Delft data steward.

The experiment has been approved by the committee with follow-up number: 2372

Chapter 9

Experiment Tuning

In order to make sure that the subjective experience of the experiment is as intended, some experiment variables had to be tuned beforehand. This tuning was performed with several students and staff, that were informed about the experiment's goal and its workings. First, the best setting for the motion filter was chosen, to ensure the motion itself felt as realistic as possible. Then, the anticipatory cueing interfaces were tuned, while using the chosen motion profile.

9-1 Simulator Motion Tuning

The simulator's motions differ from the planned motion, as its motion space is limited. Therefore, acceleration illusions using tilt had to be applied. The SRS has software to translate the planned movement into achievable movements. Tuning parameters are used in the offline motion tuning algorithm, which have a big effect on how realistic the movements feel. A good way to find the best setting for a realistic drive is to simply test them. Ten different settings were chosen for both 60 and 66 maneuvers in total and tested by a staff member that is well-known with the simulator's motions. The 66 maneuvers route was discarded as the straight parts of the road were experienced to be too short. After this, 10 different filters were compared until converging into the best option. The filter settings are based on the following equations:

$$H_{HP}(s) = \frac{s}{s + \omega_{n_{HP}}} \tag{9-1}$$

$$H_{LP}(s) = \frac{\omega_{n_{LP}}^2}{s^2 + 2\zeta_{LP}\omega_{n_{LP}}s + \omega_{n_{LP}}^2} \tag{9-2}$$

For clarity, Table 9-1 presents the range of values that were tested, while in reality, there were 10 defined settings using numbers within these ranges. The full settings for the tested scenarios can be found in Appendix B. The longitudinal and lateral accelerations of the prepositioning of the simulator stay below the 0.04 m/s^2 threshold of human perception as has been tested on the SRS by Heerspink et al. [20]. The combined acceleration vector could be higher, therefore, all movements are tested for perception.

Table 9-1: Motion Tuning Test Variables

Variable	Unit	Test options	Chosen Value
#maneuvres	-	60/66	60
K	-	0.30-0.41	0.38
ω_{HP}	rad/s	1.2-4.0	2.5
ω_{LP}	rad/s	1.5-4.8	2.5
ζ_{LP}	-	1.0	1.0
Max Tilt	deg/s	2.1-3.0	2.1
max. prep a_x	m/s^2	0.022-0.0394	0.0347
max. prep a_y	m/s^2	0.038-0.04	0.0346
MSI	%	dependent	1.97

Expected Motion Sickness Incidence (MSI)

Based on the planned motion, a MSI can be calculated with the 6DOF model of Wada et al. [40]. Since the planned motion and the actual filtered simulator motion are different, the MSI values will also differ. Since this experiment also involves an active reading task, it is expected that this calculation is lower than in practice. The graph below is based on the planned route and not on the actual simulator movements after the application of the motion filter.

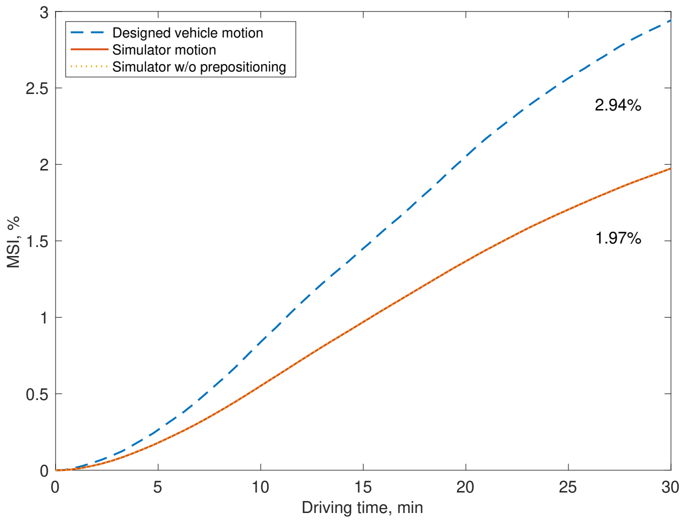


Figure 9-1: MSI Prediction of the Full Route with the 6DOF Model (Wada et al. [40])

9-2 Anticipatory Interface Tuning

In order to make sure that the anticipatory interface is experienced as intended by the concept description, another tuning session had to be performed. In order to make sure each test had the correct focus, the test subject was fully informed of the workings of the interface and was asked to specifically focus on the changing variable. The table below presents the tested variables with their final values. The actually tested combination with results can be seen in Appendix B. As some test variables give very small changes, most test variables tests were performed multiple times in different orders to ensure a consistent convergence to the chosen value. Based on the comments during the tuning test runs, some practical adjustments were made to end up with the design and routine as described in the previous chapters.

Table 9-2: Anticipatory Interface Tuning Test Variables

Variable	Unit	Test options	Chosen Value
Lead time	s	0-1.5	0.9
$K_{direction}$ moving average	s	0.01-2.01	1.51
$K_{magnitude}$ moving average	s	0.01-2.01	1.51
Color: acceleration	RGBW	Cyan like colors	[20 190 75 5]
Color: deceleration	4x 0-255	Purple like colors	[254 0 140 0]
min cue acceleration	m/s^2	0-0.2	0.2
max cue acceleration	m/s^2	3-4.5	4
pixel width max	$\#_{pixels}$	25-55	40

The timing of the cue is one of the crucial results of the tuning trial is the timing of the cues. Hereby, lead time is not stand alone, as it is affected by the lead and lag of the moving average. Therefore, several combinations were tested. The gains were tuned with focus on the smoothness and experienced comfort of the cue, while the lead time had its focus on the timing in combination with the movements of the simulator. The final values converged to a lead time of 0.9 seconds with a moving average off 1.5 seconds applied on the cues, resulting in an additional 0.75 seconds lead and lag.

Chapter 10

Discussion

Nearly each design process requires some form of iteration from the original idea to achieve the intended result. In this chapter, the iterations on the interfaces as well as the experimental conditions will be discussed.

10-1 Possible Biases

One of the biases will probably be the fact that people get more used to the simulator. Therefore, it is very likely that participants will be less negatively affected by the motion in the second trial and even less in the third. This is not really practically avoidable with a within-participants experiment. Another unavoidable bias comes from the participant's state. The amount of food, sleep, etc. can have a large effect on their susceptibility to MS. Depending on which condition the subjects will get in the first trial, they could get used to the interface or the lack of it. In the next trial, participants could have learned how the trial is with (or without) interface. This is a difficult bias to avoid and to find given the statistically limited data points, but this will be kept in mind during the analysis of the results.

Sound Interface

During the concept proposal, the experimental plan was to compare a sound-only interface with a light-only interface. This could give insight into a preference for the interface medium, which could then be further investigated. However, during the first system testing, the simulator cabin appeared to be so poorly sound insulated, that it was impossible to identify any directional information from the sound. This would probably not be in a car as most vehicles have a lot more textile or other sound-isolating materials. After this conclusion, it has been found that the interfaces were not similar enough to be compared. The choice has been made to compare the light interface with the sound and light (combined) interface, as the sound cues are very clear on longitudinal cues due to the rising and falling Shepard's tone for acceleration and deceleration. Therefore, this could potentially increase the usability or effectiveness of the light interface. Furthermore, the chosen sound could be interpreted as too intense or too loud, even though it has been tried to avoid this. For this experiment, it has been chosen to use an artificial sound that stands out to ensure that participants do not confuse the cues with simulator sounds. This design could be interpreted as annoying or even alienating. In

Light Interface

Although the colors are carefully chosen and tested, it could also be that the brightness or specific color can have an unpredicted alarming or annoying effect on the subjects. Furthermore, the light cue interface could be overstimulating or confusing when poorly timed. Especially when the subjects are reading from the LCD back-lighted tablet, this extra light could have negative effects on their general state. A lot of effects were put into the mitigation of this effect by testing and tuning. However, this was done with a small selection of people, which can not ensure it will be the same for every individual.

The linear change in RGBW code number representation is a very direct but blunt approach. By doing so, the colors change slightly when dimmed, which may give unwanted effects in the transitions of magnitude In a follow-up experiment, this can be solved using RGBW color tables that gradually change the color to black.

10-2 Other Useful Experimental Design Considerations

An experiment can always be more elaborate or detailed. However, in order to limit time and resources, some corners have to be cut. This section shortly discusses the extra measurements and conditions that could have been useful.

- Temperature *(control variable of measurement for biases)*

  Bohrmann et al. [6] has found clear correlations between temperature and Motion Sickness. However, the temperature of the SIMONA Research Simulator building can not be controlled accurately. The simulator's air conditioning system will be turned on/off on the subject's preference.

- Concentration Levels *(by survey)*

  Concentration levels do have an effect on MS, however mostly how it is perceived [6]. Letting the subject read a newspaper gives the freedom of choice and adds extra cognition of choosing rather than following a specified task. However, newspapers can create inconsistencies in how interesting the reading task is. This may result in unwanted fluctuations in concentration levels, which may also affect how the interface is perceived.

- Sweat Levels (as performed by Winkel et al. [43])

  Sweating is a common MS symptom. This could be measured at for example the fingertips and would be a more objective measurement than the MISC rating. However, this still has individual differences.

- Fixed reading task (*rather than daily changes*)

  With reading the news, there is a possibility that the reading itself is a lot more or less interesting compared to other trials. This will also be the case for a fixed reading task, however, this will be more known and controlled. The subjects are given full freedom of article choice, which should mitigate differences in personal interests.

Chapter 11

Conclusion

The interface concept has been designed to be a non-intrusive element in an everyday drive, with the aim to reduce MS symptoms without decreasing driving comfort. This experiment will compare two different interface types as well as their individual characteristics. The interfaces are specifically designed for this experiment and present cues linear to the upcoming accelerations on a surrounding LED strip or via sound. Eighteen subjects will experience a baseline, light interface, and light and sound interface in three separate trials in different orders. The pseudo-random route will be identical for all trials and consists of three different acceleration profiles, with a total of 60 maneuvers. During each trial, the MISC will be measured together with any comments. This will be the main variable to compare the trials in terms of MS mitigation. Furthermore, after each trial, subjects will answer an electronic survey which consists of questions about their subjective experience, MS symptoms, and trial preference.

Resulting from the tuning experiment, conclusions were made about the preferred cue timing. It is important to mention, this was tested with a small number of subjects in a non-experiment tuning setup. Therefore it is not statically relevant. The experiment's survey includes a question on the timing, which will be used to check its validity. In these specific settings, the cue timing is preferred to be 0.9s, given a 1.5s moving average applied on the cues, thus a 0.75s lead in addition to the 0.9s.

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Appendix A

Experiment Checklists

(Graded for the AE4020 Course)

This checklist is made for starting up the simulator and making sure everything is properly prepared for the experiment, followed by the experiment routine.

Morning Routine

Checklist SIMONA experiment

Start of day

Find your supervisor of the day

Control room start of experiment:

- ❒ **Fill in the form for SIMONA operation**
- ❒ Control room screens turned ON
- ❒ Tablet and XSense charged/charging

SIMONA control panel: *Activation → System*:

- ❒ EFIS2 **ON**
- ❒ Sound-system **ON**
- ❒ Ambient light strip **ON**

SIMONA cabin:

- ❒ Ensure sick bags are available within reach of participant's simulator seat
- ❒ Turn on the sound system and at right volume
  - Bass at 2 full spot
  - Full 5.1 at middle full spot

Motion system:

- ❒ Visual check if ready → Environment ready (button)
- ❒ Bridge disconnect
- ❒ Motion system **ON**
  - **Do not forget to write down time!!**
  - During warmup, ΔP should be around 110 bar (warm-up)
  - If ΔP around 160 bar, turn OFF → wait → ON again
- ❒ Turn projectors **ON**
  - Not too early, max 20 min before first participant to save light hours
  - **Do not forget to write down time!!**
  -

After the system has warmed up:

- ❒ Taking SIMONA of the buffers
  - Environment ready
  - Select all
  - CManual
  - Small ticks on UP → continuous UP until almost halfway → continuous DOWN again
  - CManual End
  - After taking out of buffers, ΔP should be around 160 bar
- ❒ Turn of motion, return bridge and open fence

VERY IMPORTANT: GET SOME COFFEE

Experiment session

(Safety) briefing *(only first session)*:

- ❒ SIMONA safety video
- ❒ Experiment briefing
- ❒ Informed consent **(2x!)**
- ❒ Explain communication

--------------------------------------Time for the Briefing Form--------------------------------------

Start of experiment session:

- ❒ Check environment
- ❒ Check communication
- ❒ Seatbelt low on stomach
- ❒ **Apply right experiment condition in dueca.mod**
    - *Configuration TRUE:*
        - ▪ *All True except: record_on_device & log_debug_motion*
        - ▪ Visual mode = 6
    - *Correct MISC language (English/Dutch)*
- ❒ Shuttle Door Open / Seatbelts Unfastened lights turned OFF
- ❒ Bridge disconnect
- ❒ Motion system ON
    - Depending on time motion system has been OFF, take SIMONA out of buffers with participant in the seat (± >70min)
- ❒ **IF** motion_system fails: Reset Host2MCCEXPERIMENTAL
- ❒ **IF** alarms on Simulink: confirm alarm, reset alarms

Start experiment

- ❒ **Go to work**
    - Screens will change
- ❒ **Go to hold**
    - Motion will start
    - XSence calibrate – Head straight forward
- ❒ **Go to Advance**
    - Ask if ready / tablet okay
    - Ask first MiSc score
    - Stop at MISC=7 OR (MISC=6 AND MISC(n-1)=6)

End of experiment session:

- ❒ Wait with seatbelt until motion system off
- ❒ Go back to SAFE (do NOT close DUSIME control panel)
- ❒ Motion system OFF
    - **Do not forget to write down time!!**
- ❒ Bridge connect
- ❒ Only quit DUSIME control panel once participant is leaving SIMONA
- ❒ Qualtrics
- ❒ Talk about information management!!!

End of day

- ❒ Visual system OFF
    - After last participant leaves SIMONA
        - ▪ if nothing else is planned in SIMONA that day
    - **Do not forget to write down time!!**

Experiment routine

Appendix B

Tuning Experiment Settings

(Graded for the AE4020 Course)

The following 2 documents are about the tuning of the experiment settings. Starting with the tuning of the simulator motion, followed by the tuning of the exact setting for the anticipatory cue interface.

- Motion filter cueing settings tests and results
- Anticipatory cueing interface tests and results

FINAL MOTION FILTER SETTINGS

60 manoeuvres

Motion filtered as if motion cues experienced in left simulator seat correspond to the motion felt in the vehicle's left front seat, i.e., 0.4 [m] to the left of the vehicle's center of gravity.

	K (-)	**ω_{HP} (rad/s)**	**ω_{LP}, (rad/s)**	**ζ_{LP} (-)**	**Max. tilt (deg/s)**	**X / Y (m) type 1 acc.**	**X / Y (m) type 1 dec.**	**X / Y (m) type 2**	**X / Y (m) type 3**	**Prep. margin (s)**	**t_{jerk} (s)**	**Max. prep. a_x / a_y (m/s^2)**	**MSI (%)**	**Comments**
4	0.38	2.5	2.5	1.0	2.1	0.0 / 0.0	0.0 / 0.0	-0.07 / 0.26	0.0 / 0.0	2.6 / 0.05	0.40	0.0347 / 0.0346	1.97	

*Motion filter settings on the next two pages, tested in the SIMONA Research Simulator, filtered the motion such that motion cues experienced in left simulator seat correspond to the motion felt in the vehicle's left back seat, i.e., 1.0 [m] behind and 0.5 [m] to the left of the vehicle's center of gravity.

60 manoeuvres

	K (-)	ω_{HP} (rad/s)	$\omega_{LP,}$ (rad/s)	ζ_{LP} (-)	Max. tilt (deg/s)	X / Y (m) type 1 acc.	X / Y (m) type 1 dec.	X / Y (m) type 2	X / Y (m) type 3	Prep. margin (s)	t_{jerk} (s)	Max. prep. a_x / a_y (m/s^2)	MSI (%)	Comments
1	0.41	3.0	1.5	1.0	3	0.0 / 0.0	0.0 / 0.0	-0.14 / 0.25	0.0 / 0.0	3.0 / 0.05	0.45	0.0220 / 0.0396	2.28	Feels pretty good. Sideways motion feels perfect. A little bit more “swing-like”/tilt than settings 2 with max. tilt of 2.5 deg/s.
1	0.40	3.0	1.5	1.0	2.5	0.0 / 0.0	0.0 / 0.0	-0.14 / 0.25	0.0 / 0.0	3.0 / 0.05	0.45	0.0240 / 0.0395	2.06	Does not feel much different from settings 1 with max. tilt of 3 deg/s directly above.
2	0.37	2.0	4.0	1.0	3	0.0 / 0.0	0.0 / 0.0	-0.15 / 0.28	0.0 / 0.0	2.6 / 0.05	0.45	0.037 / 0.038	2.59	Perhaps feels a little bit milder than settings 1 above, but still wondering whether settings 1 feels a tiny bit better?
2	0.35	2.0	4.0	1.0	2.5	0.0 / 0.0	0.0 / 0.0	-0.09 / 0.28	0.0 / 0.0	2.6 / 0.05	0.45	0.0386 / 0.0380	2.17	Feels fine, a bit better than settings 1, as it feels less “swing-like”. Pitches a little bit more at the end than settings 4 with max. tilt of 2.1 deg/s.
2	0.35	2.0	4.0	1.0	2.2	0.0 / 0.0	0.0 / 0.0	-0.03 / 0.295	0.0 / 0.0	2.5 / 0.05	0.45	0.0396 / 0.0386	1.97	Little jolt between deceleration and turn in aggressive acceleration profile.
3	0.31	1.4	4.2	1.0	3	0.0 / 0.0	0.0 / 0.0	-0.225 / 0.225	0.0 / 0.0	2.6 / 0.05	0.45	0.0386 / 0.0392	2.08	Too much pitch during acceleration.
4	0.39	2.5	2.5	1.0	3	0.0 / 0.0	0.0 / 0.0	-0.125 / 0.295	0.0 / 0.0	2.6 / 0.05	0.45	0.0237 / 0.0400	2.59	“Keeps going” for too long.
4	0.39	2.5	2.5	1.0	2.5	0.0 / 0.0	0.0 / 0.0	-0.11 / 0.295	0.0 / 0.0	2.6 / 0.05	0.45	0.0329 / 0.0400	2.33	Little jolt in the aggressive acceleration profile.
4	0.38	2.5	2.5	1.0	2.1	0.0 / 0.0	0.0 / 0.0	-0.10 / 0.28	0.0 / 0.0	2.6 / 0.05	0.45	0.0394 / 0.0380	1.98	Feels better than settings 2 with a max. tilt of 2.5 deg/s. Feels like smooth driving. **Best settings.**
5	0.30	1.2	4.8	1.0	3.0	0.0 / 0.0	0.0 / 0.0	-0.225 / 0.205	0.0 / 0.0	2.55 / 0.05	0.45	0.0392 / 0.0392	2.01	“Swings” too much.

66 manoeuvres (TOO MANY manoeuvres; time interval between manoeuvres TOO SHORT)

	K (-)	ω_{HP} (rad/s)	$\omega_{LP,}$ (rad/s)	ζ_{LP} (-)	Max. tilt (deg/s)	X / Y (m) type 1 acc.	X / Y (m) type 1 dec.	X / Y (m) type 2	X / Y (m) type 3	Prep. margin (s)	t_{jerk} (s)	Max. prep. a_x / a_y (m/s^2)	MSI (%)	Comments
1	0.40	3.0	1.5	1.0	3	0.0 / 0.0	0.0 / 0.0	-0.17 / 0.20	0.0 / 0.0	2.6 / 0.05	0.45	0.0325 / 0.0378	2.42	Relatively good.
1	0.40	3.0	1.5	1.0	2.5	0.0 / 0.0	0.0 / 0.0	-0.15 / 0.21	0.0 / 0.0	2.6 / 0.05	0.45	0.0312 / 0.0398	2.26	Not tested.
1	0.39	3.0	1.5	1.0	2.1	0.0 / 0.0	0.0 / 0.0	-0.15 / 0.195	0.0 / 0.0	2.6 / 0.05	0.45	0.0364 / 0.0369	2.00	Not tested.
2	0.35	2.0	4.0	1.0	3	0.0 / 0.0	0.0 / 0.0	-0.125 / 0.20	0.0 / 0.0	2.55 / 0.05	0.45	0.0399 / 0.0391	2.66	Better than 1.
2	0.32	2.0	4.0	1.0	2.5	0.0 / 0.0	0.0 / 0.0	-0.08 / 0.22	0.0 / 0.0	2.55 / 0.05	0.45	0.0372 / 0.0398	2.16	Not tested.
3	0.29	1.4	4.2	1.0	3	0.0 / 0.0	0.0 / 0.0	-0.16 / 0.12	0.0 / 0.0	2.6 / 0.05	0.45	0.0364 / 0.0390	2.08	Not tested.
4	0.38	2.5	2.5	1.0	3	0.0 / 0.0	0.0 / 0.0	-0.17 / 0.205	0.0 / 0.0	2.55 / 0.05	0.45	0.0393 / 0.0398	2.76	Not tested.
4	0.37	2.5	2.5	1.0	2.5	0.0 / 0.0	0.0 / 0.0	-0.115 / 0.215	0.0 / 0.0	2.55 / 0.05	0.45	0.0399 / 0.0396	2.33	Not tested.
4	0.36	2.5	2.5	1.0	2.1	0.0 / 0.0	0.0 / 0.0	-0.05 / 0.205	0.0 / 0.0	2.55 / 0.05	0.45	0.0392 / 0.0378	1.98	Not tested.
5	0.27	1.2	4.8	1.0	3.0	0.0 / 0.0	0.0 / 0.0	-0.10 / 0.10	0.0 / 0.0	2.55 / 0.05	0.45	0.0330 / 0.0389	1.91	Not tested.

	Cue Focus	File num	Lead time	Mov avi dir	Mov avg mag	Color dec	Color acc	Max angle	Split angle	Acc min	Acc full	Pixels width	Volume ratio	Comments
			[s]	Total avg [ms]	Total avg [ms]	RGBW	RGBW	[deg]	[deg]	[m/s2]	[m/s2]	#pixels @full	0-1 vs. engine	
Lead time More tests have been performed and finally converged to 0.9s with given lead/lag settings	**No lead**	1SL	0	151	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	
	Very high lead	1SL	1.5	151	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	Too early
	Low lead	1SL	0.3	151	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	Much more natural
	High lead	1SL	1.2	151	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	More iterations needed
	Medium lead	1SL	0.6	151	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	Different manoeuvres difficult
	Normal lead	1SL	1	151	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	Felt equal to corners
DIR central moving average	**Mov avg dir [0]**	2SL	1	1	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	Too fast -> confusing
	Mov avg dir low	3SL	1	201	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	A lot more natural
	Mov avg dir medium	4SL	1	101	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	201 is better
	Mov avg dir high	5SL	1	151	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	A lot more natural; more direct then 201
Mag central moving average	**Mov avg mag**	6SL	0.9	151	1	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	Felt good
	Mov avg mag medium	7SL	0.9	151	151	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	Better, more relaxed
	Mov avg mag high	8SL	0.9	151	51	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1	More extreem
Color	**Colors 1**	9L	0.9	151	151	[254 20 210 20]	[30 200 180 20]	60	38	0.2	4	40	1	Accel color too white
	Colors 2	10L	0.9	151	151	[254 0 110 10]	[30 200 180 20]	60	38	0.2	4	40	1	Check for too much redness: alarming

	Cue Focus	File num	Lead time	Mov avi dir	Mov avg mag	Color dec	Color acc	Max angle	Split angle	Acc min	Acc full	Pixels width	Volume ratio	Comments
			[s]	Total avg [ms]	Total avg [ms]	RGBW	RGBW	[deg]	[deg]	[m/ s2]	[m/ s2]	#pixels @full	0-1 vs. engine	
	Colors 3	11L	0.9	151	151	[254 30 230 0]	[20 250 150 20]	60	38	0.2	4	40	1	Not comfortable
Angles of cue presentation	**No max angle**	12L	0.9	151	151	[254 0 254 40]	[0 120 80 30]	90	38	0.2	4	40	1	Clearly less comfortable
	Medium max angle	13L	0.9	151	151	[254 0 254 40]	[0 120 80 30]	50	30	0.2	4	40	1	Worse than previous
	Small max angl	14L	0.9	151	151	[254 0 254 40]	[0 120 80 30]	70	38	0.2	4	40	1	More movement: better
	Small split	15L	0.9	151	151	[254 0 254 40]	[0 120 80 30]	60	30	0.2	4	40	1	Better to be position in front of seat (cue)
Acceleration limit of cue	**Min acc = 0**	16SL	0.9	151	151	[254 0 254 40]	[0 120 80 30]	60	38	0	4	40	1	No difference
	Full cue low	17SL	0.9	151	151	[254 0 254 40]	[0 120 80 30]	60	38	0.2	3	40	1	
	Acc max full	18SL	0.9	151	151	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4.5	40	1	More intense
Pixels width	**Pixels width low**	19L	0.9	151	151	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	25	1	More comfortable - white color bias
	Pixel width high	20L	0.9	151	151	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	55	1	Intrusive
Volume test	**Vol ratio low**	21S	0.9	151	151	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	0.8	More precisely tuned afterwards
	Vol ratio high	22S	0.9	151	151	[254 0 254 40]	[0 120 80 30]	60	38	0.2	4	40	1.3?	
Light lowering during sound	**Light x0.5**	23SL	0.9	151	151	[254 0 140 0]	[20 190 75 5]	60	38	0.2	4	30	1	
	Light x0.25	24SL	0.9	151	151	[254 0 140 0]	[20 190 75 5]	60	38	0.2	4	20	1	Low intensity changed colours
	Light x0.1	25SL	0.9	151	151	[254 0 140 0]	[20 190 75 5]	60	38	0.2	4	12	1	Not worth the bias

Appendix C

Briefings

(Graded for the AE4020 Course)

The following pages contain the information that all subjects received before the experiments

- Emails
- Informed Consent From
- Experiment Briefing
- Verbal Experiment Briefing Routine

Motion Comfort Experiment Invitation:

- Experiment Briefing PDF

Dear Participant,

Thank you for filling in my survey,
I would like to invite you to participate in my experiment on motion comfort.
The experiments briefing is attached, to get a better understanding of the expectations.

In order to plan your trial as fast and well as possible, try to give a broad window of your availability these coming weeks and reply fast. The planning is made in order of replies.
Please indicate the timeslots that you are available:
e.g.
Monday 17 October 9-14h
Tuesday 18 October 12-18h
Thursday 20 October 8-14h
Friday 21 October 8:30-15h
Etc.
I will try to respond as fast as possible and let you know what days and times you will be expected.

Best regards,
Wouter Spek

---------------------- Nederlands ----------------------

Dear Participant,

Bedankt voor het invullen van mijn enquête,
Ik wil je graag uitnodigen voor mijn experiment over bewegingscomfort.
De experimentenbriefing is bijgevoegd om een beter inzicht te krijgen wat je kan verwachten.

Om je proef zo snel en goed mogelijk in te plannen, wil ik graag je beschikbaarheid van de komende weken weten. De planning wordt gemaakt in volgorde van antwoord en beschikbaarheid.
Geef a.u.b. aan op welke dagen en tijdstippen je beschikbaar bent:
bijv.
Maandag 17 Oktober 9-14u
Dinsdag 18 Oktober 12-18u
Donderdag 20 Oktober 8-14u
Vrijdag 21 Oktober 8:30-15u
Etc.
Ik zal proberen zo snel mogelijk te reageren en laten weten welke dagen en tijden je ingepland wordt.

mvg,
Wouter Spek

Motion Comfort Experiment Planning:

- 3 dates and times
- Experiment Briefing
- Informed consent
- Safety video:
    - https://www.youtube.com/watch?v=PXijsyJ3hro

-------------------------- Scroll door voor Nederlands --------------------------

Dear Participant,

Thank you for your availability. I have planned you in for the 3 different sessions.

Trial 1: ±90min
Monday 17 October 13:00
Trail 2: ±60min
Wednesday 19 October 9:00
Trail 3: ±70min
Friday 21 October 11:00

Please let me know if you will be participating in these timeslots and mark them in your personal calendar.

Location: https://goo.gl/maps/XchyCUWgZwMoP2Wi9
The experiment will take place at the SIMONA Research Simulator at the Faculty of Aerospace Engineering. The location can be reached via the C&S entrance (maps location) or via the Aerospace main entrance. Please call me when you are at the door with my phone number below, as I have to let you in. Please let me know if you prefer any other location for me to pick you up.

Expectation:
You can find the briefing PDF attached to this email. After you arrive for the first trial, we will go through a more detailed briefing of the experiment. All procedures will be discussed, and I you understand and agree, we will continue with the necessary paperwork that states your consent for using your (anonymous) results of the experiment. After this, I will talk you through all steps in the progress of the simulator run in the SIMONA Research Simulator. The second and third trial require a shorter start-up time.

Preparation:
Being fit for the trials is also important since the experiment is about comfort. Therefore, (excessive) alcohol or drugs use in the 24h before each experiment trial is strongly discouraged. In order to have the best experience, make sure that you have eaten before the trial and that you are well rested.

SIMONA safety video: https://www.youtube.com/watch?v=PXijsyJ3hro
Before participating in the experiment trials, it is important to watch the SIMONA safety video and read the briefing and the informed consent form. It is allowed to do this on location, however, it is faster and may be more convenient to do this before the first trial.

Corona
Please be aware that this experiment will follow the corona guideline set by the faculty, which may be more strict than you may expect. We will try to keep our distance during the experiment and avoid close contact. Please check if you have any COVID-19-related symptoms beforehand, please let me know as the experiment will then be rescheduled.

Cancelation:
If you cannot participate for any other reason, please let me know in advance. You do not have to state a reason, we can check if another timeslot would fit.

If you have any other questions beforehand, please let me know via email or by phone (below).

See you soon and best regard,
Wouter Spek
+316xxxxxxxx

----------------------- Nederlands -----------------------

Beste deelnemer,

Bedankt voor uw beschikbaarheid. Ik heb je ingepland voor de 3 verschillende sessies.
<Zie sessies bovenaan email>

Laat het me weten als je kan deelnemen op deze tijdsloten en zet ze in je persoonlijke agenda.

Locatie: https://goo.gl/maps/XchyCUWgZwMoP2Wi9
Het experiment vindt plaats in de SIMONA Research Simulator van de faculteit Lucht- en Ruimtevaarttechniek. De locatie is te bereiken via de C&S entree (plattegrond locatie) of via de Aerospace hoofdingang. Bel me alsjeblieft als je voor de deur staat (onder aan de mail), want ik moet je binnenlaten. Als je voorkeur heb voor een andere plek om aft te spreken, laat het me dan vooral weten.
Verwachting:
De briefing-pdf zit als bijlage bij deze e-mail. Nadat u bent aangekomen voor de eerste proef, zal ik een gedetailleerde briefing van het experiment geven. Alle procedures zullen worden besproken, en als je alles begrijpt en ermee instemt, zullen we doorgaan met het benodigde papierwerk waarmee je toestemming geeft voor het gebruik van uw (anonieme) resultaten van het experiment. Daarna gaan we samen door alle stappen van de simulator heen. Bij de tweede en derde proef is er minder voorbereidingstijd nodig
Voorbereiding:
Fit voelen is belangrijk voor die experiment, omdat het over comfort gaat. Daarom wordt (overmatig) alcohol- of drugsgebruik in de 24 uur voorafgaand aan elk experiment deel sterk afgeraden. Om de beste ervaring te hebben, kan je het beste goed hebben gegeten en uitgerust aankomen.
SIMONA veiligheidsvideo: https://www.youtube.com/watch?v=PXijsyJ3hro
Voordat je de simulator in mag, is het belangrijk om de SIMONA-veiligheidsvideo te bekijken en de briefing en het geïnformeerde toestemmingsformulier te lezen. Het is toegestaan om dit op locatie te doen, maar het is sneller en wellicht handiger om dit voor de eerste proef te doen.
Corona

Houd er rekening mee dat dit experiment de door de faculteit gestelde coronarichtlijn zal volgen, die strenger kan zijn dan je zou verwachten. We zullen tijdens het experiment afstand proberen te houden en nauw contact vermijden. Controleer van tevoren of u COVID-19-gerelateerde symptomen heeft, laat het me weten, want dan moet het experiment worden verplaatst.

Annulering:

Mocht je om een andere reden niet kunnen deelnemen, laat het me dan van tevoren weten. Je hoeft geen reden op te geven en we kunnen kijken of een ander tijdslot beter zou passen.

Als je vooraf nog andere vragen hebt, laat het me dan weten via e-mail of per telefoon (hieronder).

Tot snel en met vriendelijke groet,

Wouter Spek
+316xxxxxxxx

Reminder Experiment trial participation:

Dear,

Tomorrow you will be expected at an experiment trial on the Motion Comfort experiment at the Faculty of Aerospace Engineering. Please refer to prefer email with subject:
Motion Comfort Experiment Planning
For more information

If by any reason, you need to cancel, please let me know.

Best regards and see you Tomorrow,
Wouter Spek
+316xxxxxxxx

----------------------- Nederlands -----------------------

Morgen wordt je verwacht bij een bewegings comfort experiment op de Lucht- en Ruimtevaarttechniek faculteit. Zie de eerder mail met onderwerp:
Motion Comfort Experiment Planning
voor meer informatie.

Als je toch verhinderd ben, hoor ik het graag.

Mvg en tot morgen,
Wouter Spek
+316xxxxxxxx

Experiment survey reaction:

Dear,

Thank you for filling in my survey for the Motion Comfort experiment.
I have read your reaction and based on the results of your motion susceptibility I will currently not be inviting you for the experiment.
Therefore you will be placed on the reserve list and you will be contacted later if needed.
If you have questions or if you do not agree with the selection, please let me know.

Best regards,
Wouter Spek

Experiment Consent Form – Investigating Motion Comfort in Automated Vehicles

Please tick the appropriate boxes	**Yes**	**No**
I have read and understood the experiment briefing, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	□	□
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	□	□
I understand that I will be compensated for my participation in the form of a Bol.com gift card with €10,- credit for each experiment session that I attempt. This is independent of whether I decide to withdraw from the study before having taken part in all experiment sessions, or whether an experiment session is aborted prematurely. It also does <u>not</u> depend on any of my answers provided during the study.	□	□
I understand that taking part in the study involves being asked to provide verbal feedback on my motion discomfort development on a frequent basis, while being exposed to simulator motion.	□	□
I understand that taking part in the study involves the risk of developing temporary physical and/or mental discomfort caused by being exposed to simulator motion, as the goal of the experiment is to investigate the motion (dis)comfort development of vehicle passengers.	□	□
I confirm that the researcher has provided me with detailed safety and operational instructions for the SIMONA Research Simulator and that these instructions are fully clear to me.	□	□
I confirm that the researcher has provided me with detailed safety instructions to ensure my experiment sessions can be performed in line with current RIVM COVID-19 regulations *at all times* and that these instructions are fully clear to me.	□	□
I understand that information I provide will be used for scientific reports and/or publications, in which the researcher will <u>not</u> identify me by name, and that my confidentiality as a participant in this study remains secure.	□	□
I understand that personal information collected about me that can identify me, such as my name and my age, will <u>not</u> be shared beyond the study team.	□	□
I understand that this research is funded by and performed in collaboration with an industry partner, who will <u>not</u> receive any personal data collected in this research.	□	□
I give permission for the <u>anonymized</u> motion discomfort history questionnaire, symptoms checklists, verbal motion discomfort ratings and other comfort questionnaires that I provide to be archived in a secure data repository, so they can be used for future research and learning.	□	□
I understand that at all times I can request for my participant data to be removed from the secure data repository.	□	□
I understand that this research study has been reviewed and approved by the TU Delft Human Research Ethics Committee (HREC). I am aware that I can report any problems regarding my participation in the experiment to the researcher using the contact information below.	□	□
I confirm that I currently do not have any COVID-19 symptoms.	□	□

Signatures

________________________________	_______________________	________________	Part. no.: _________
Name of participant	Signature	Date	(Filled out by researcher)

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Wouter Spek____________________	_______________________	________________
Researcher name	Signature	Date

Contact responsible researcher:	Wouter Spek		<Phone numbers>
Contact research supervisor:	Rowenna Wijlens	__________________	

Experiment Briefing
Investigating Motion Comfort in Automated Vehicles

First of all, thank you for taking part in this experiment! You will be participating in a motion experiment in the SIMONA Research Simulator (SRS) at the Faculty of Aerospace Engineering of the TU Delft. This briefing will provide you with a short introduction on what to expect and what is expected from you as a participant.

Your participation in this experiment is completely voluntary, which means you have the right to withdraw from the experiment at any given time without having to give a reason. The experiment has been approved by the *Human Research Ethics Committee* of the TU Delft and will be performed in line with current RIVM COVID-19 regulations at all times as well as with additional guidelines of the faculty and facility. All data collected during this experiment will, of course, be made completely anonymous, but can still always be deleted on your request.

The experiment will consist of **three separate experiment sessions**. We would like to ask you not to discuss the experiment with any other participants before they, as well as you, have completed all three sessions, as this could influence the experiment results. There will be a baseline trial and 2 trials with light- and sound-based interfaces, that will provide low-level information about the route and/or movements.

Experiment Goal

The goal of this experiment is to investigate passengers' motion comfort in self-driving vehicles, including their interaction with different in-vehicle driving environment concepts for vehicle comfort. The results of this experiment can be used to make recommendations on self-driving vehicle design to ensure that passengers feel as comfortable as possible during a ride. You will be asked to review each trial and compare the 3 trials at the end.

Experiment Procedures

The experiment will consist of three separate experiment sessions, which will take place a few days apart. Each session will take **approximately *60 to 75 minutes***. All sessions will consist of a preparation, a motion exposure in the simulator, and afterward, the filling in of a motion discomfort symptoms checklist and questionnaires on the used driving environment concept for vehicle comfort regarding its effectiveness, intuitiveness, comfort, and intrusiveness. In all sessions, you will be exposed to [30 minutes] of simulator motion. The time schedule for the three experiment sessions is shown below.

Introduction (only the first session)	**Briefing**	**Simulator motion**	**Verbal ratings**	**Questionnaires**
±15 min	±5 min	30 min	±5 min (every 30 s)	±15/20 min

Experiment Tasks / Expectations

The experiment will simulate a condition where you are a passenger of a self-driving vehicle, and you are trying to work while traveling on the road. Therefore, you do not have to provide any steering or gas/brake pedal inputs. Instead, you will be asked to read a text (newspaper) on a tablet and you will have no visual on the road.

<u>The tasks for you as a participant during your time in the simulator are as follows:</u>

- Enjoy the ride!
- Read the paper on the tablet at your own pace and preference.
- Do not look around or make unnecessary head movements, especially during maneuvers. Your head movements are measured only during the 30min. Thus you can look around before or after the 30min drive.
- Every 30 seconds, you will be notified with a beep that you are requested to verbally state your motion discomfort level on the scale that is presented in front of you. After 5min, this will be every minute.
- For 5 minutes directly after the simulator motion has ended, you will be asked to remain seated and requested every 30 seconds to verbally state how you feel. (you can stop reading then).

Please remember that you have the right to stop at any given moment. The researcher may also make this decision for you, if this seems better for you. It is *not* the goal to get you very nauseous or sick.

Lastly, thank you for your participation and do not hesitate to contact us in case of any questions or remarks!

Contact responsible researcher:	Wouter Spek	W.J.Spek@student.tudelft.nl	<phone numbers>
Contact research supervisor:	Rowenna Wijlens	R.Wijlens@tudelft.nl	

Verbal experiment Briefing checks

Verbal experiment Briefing checks

Experiment briefing

- ❐ **Safety video** SIMONA (seen or not)
- ❐ Have you read the experiment briefing?
- ❐ General idea of being driven around a set trajectory and reading the paper
- ❐ Communication procedures
- ❐ Visuals: artificial horizon
- ❐ **Tablet:** read the paper at your own preference – keep reading
- ❐ Try to assume a relaxed posture
    - Try to limit your unnecessary movements
- ❐ **IMU:** You will be asked to wear a band with an IMU (Inertial Measurement Unit)
    - Keep this on your forehead
    - Look straight ahead at the start to correctly calibrate the sensor
- ❐ **MISC Ping:** You will be asked to provide a MISC score every 30/60 seconds
    - First 5min: every 30 seconds – next 25min: every 60 seconds
    - After the route 5min – **without reading**
    - Explain MIsery SCale
        - Provide <u>highest number</u> you felt since the last reporting of the MISC score
    - You will hear a 'ping' sound asking to verbally report your current MISC score
    - I will write the MISC score down on a score card
- ❐ **Head:** Try not to actively move your head more then necessary for reading
    - <u>Do not look around!!!</u>
    - Passive movement due to simulator motion is normal – see picture
    - Except for when you would like to have a look at the MISC scale
- ❐ **Stop:** Right to request the termination of the experiment at any time
    - Independent of your MISC score (whether this is a 0 or a 3, for example)
    - I will immediately stop the experiment if you verbally ask to do so
- ❐ **Stop how?** If you want an immediate stop, use the red emergency button
    - Less comfortable, may to more time to get you out. But stops very immediately
    - If you just let me know verbally that you would like to stop, I will always carry out that request and stop SIMONA with the normal procedure
- ❐ **Sick bags** are available in SIMONA in case you might need them
    - Aim is to stop the experiment well before you reach that moment at which you would feel you might need to use them
- ❐ **After motion**
    - During these 5 minutes, it would be preferred if you could remain seated in SIMONA, <u>you can stop reading</u>
    - During this 5min, I will also stop the simulator and move the bridge, such that you can go out immediately after this.
    - If necessary, it is possible to get out before the end of the 5 minutes
    - **Leave seatbelt on** until Motion System is off
- ❐ **Emergency:** please follow the instructions in the safety video you just watched. These instructions are always more important than my instructions
- ❐ Watch out when entering / exiting SIMONA to not to hit your head

During selection:

- MS Susceptibility Questionnaire (short)
- Sex
- Age

First trial information:

- Experiment consent form (2x)
- General participant info: sex; age;
- SIMONA safety video

Before experiment:

- Write down relevant comments

In control room:

- **Apply** correct motion condition
- **Apply** correct language MISC
- **Ask** MISC score before going to ADVANCE
- **Charge** tablet and IMU

After experiment:

- Computer: ATM-lab
  - MS symptom checklist
  - Motion assessment questionnaire
  - Motion comparison questionnaire
- **Give the 10euro Bol.com Voucher**

!! DO NOT FORGET TO RETRIEVE HEAD TRACKING DATA !!

General checks during session

Appendix D

Misery Scale

(Graded for the AE4020 Course)

- MIsery Scale as presented in the simulator during the experiment
- Experimental results card

English

Symptoms		**MISC**
No problems at all		0
Uneasy (no typical symptoms)		1
Dizziness, warmth, headache, stomach awareness, sweating, …, but NO nausea	vague	2
	slight	3
	fairly	4
	severe	5
Nausea	slight	6
	fairly	7
	severe	8
	(near) retching	9
Vomiting		10

MIsery SCale (MISC) rating card
Modulating motion sense in automated vehicles

Participant number:	**Trail 1:** B / L / L S	**Trail 2:** B / L / LS	**Trail 3:** B / L / LS
______	**Date: _________ /2022**	**Date: _________ /2022**	**Date: _________ /2022**
Age: ____ M / V / X	**Start time: ____:____**	**Start time: ____:____**	**Start time: ____:____**

Motion											***Recovery***				
no phone		**T1**	**T2**	**T3**	Lights out		**T1**	**T2**	**T3**			**T1**	**T2**	**T3**
0	0:00				25	20:00								
1	0:30				26	21:00				1 / 36	(3)0:30			
2	1:00				27	22:00				2 / 37	(3)1:00			
3	1:30				28	23:00				3 / 38	(3)1:30			
4	2:00				29	24:00				4 / 40	(3)2:00			
5	2:30				30	25:00				5 / 41	(3)2:30			
6	3:00				31	26:00				6 / 42	(3)3:00			
7	3:30				32	27:00				7 / 43	(3)3:30			
8	4:00				33	28:00				8 / 44	(3)4:00			
9	4:30				34	29:00				9 / 45	(3)4:30			
10	5:00				35	30:00				10 /46	(3)5:00			
11	6:00				Comments Trail 1:									
12	7:00													
13	8:00													
14	9:00													
15	10:00													
16	11:00				Comments Trail 2:									
17	12:00													
18	13:00													
19	14:00													
20	15:00				Comments Trail 3:									
21	16:00													
22	17:00													
23	18:00													
24	19:00													

Appendix E

Selection Survey

(Graded for the AE4020 Course)

This appendix presents the Selection Survey that was distributed. Based on this survey, subjects were selected and contacted for participation in the experiment.

Introduction

Welcome to the survey for participation in a Motion Comfort experiment.
This survey will take approximately 7 minutes

This entire research is performed to gather data for the MSc thesis research of Wouter Spek. The experiment takes place at the TU Delft Aerospace faculty under supervision of *Prof. Dr. Ir. Max Mulder, Dr. Ir. Rene van Paassen* and *PhD candidate Rowenna Wijlens*. The purpose of the experiment is to create a better understanding of passengers' comfort in autonomously driving vehicles.

Autonomously driving vehicles are getting more realistic in the near future. In autonomously driving vehicles, it would be possible to perform other tasks while driving. However, every new technology comes with its own downside, as the incidence of motion sickness increases with a decrease in driving interaction. Therefore, in order to increase the acceptance of autonomously driving vehicles, it is important to have a better understanding of the way how humans experience motion sickness as passengers in driving vehicles. With a better understanding, vehicles can be engineered to decrease any possible discomfort of driving, which will allow better societal acceptance.

In order to gather data, an experiment will take place in the **SIMONA Research Simulator** at the Aerospace Engineering faculty of the TU Delft. The experiment consists of **3 separate trials**, planned on 3 separate days. Each trial will take between 60-90min in which each trial, the participant will drive a 30min route in the simulator. For each actively participated trial, you will receive a 10euro voucher for your time.

The data of this survey will be used to select the participants most suitable to participate in the experiment. The experiment output will be made anonymous, however, for scheduling purposes, it is required to provide your email address. To ensure privacy, all external contact is done using TU Delft supported software or (email) servers

As with any online activity, the risk of a data breach is small but always possible. To the best of our ability, your answers in this study will remain confidential. We will minimize any risks by utilizing Qualtrics, which is a tool that is GDPR compliant and centrally procured and supported by the TU Delft, as well as by deleting your response form as soon as the experiment ends or sooner, upon your request. Furthermore, only the main researcher will have access to your response form. None of the personal data you provide (e-mail address and, optionally, phone number) will be shared with any other party. Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. Your response form as well as any contact details that you will provide (e.g. e-mail address) will be deleted as soon as the experiment ends or sooner, upon your request.

If you have any questions, please feel from to contact me:

Wouter Spek
W.J.Spek@student.tudelft.nl
<phone number>

Available?

This experiment consists of three separate trials on three separate days. For each actively participated trial, you will receive a 10euro voucher to compensate you for your time. If you are invited based on (the results of) this questionnaire, you will receive more detailed planning with all trial options.

Continuing this survey will only be useful if you will be available for **3 days**

within a 7-10 day period, for 60-90min on location in the Aerospace Faculty in Delft, between Oktober 3 and Oktober 21 (week 40+41+42)

You will be contacted for the exact planning based on the results of the survey

- ○ **Yes**, I am very flexible, thus this should fit in my scedule
- ○ **Maybe**, I will try to fit the 3 trials in, but am not sure yet
- ○ **No**, I will not be available for 3 separate trials in these 3 weeks

Basic info

1/6 - How susceptible to motion sickness do you consider yourself to be? (select 1)

- ○ **Not susceptible** at all (i.e. I have never experienced motion sickness in my life)
- ○ I have **low susceptibility** to motion sickness (i.e. I would very rarely get motion sick when
traveling by car, boat, plane, or another mode of transportation)
- ○ I have **medium susceptibility** to motion sickness (i.e. I sometimes get sick when traveling -
especially, for example, when traveling by car on winding roads or when traveling by plane and
there is a lot of turbulence)
- ○ I have **high susceptibility** to motion sickness (i.e. I almost always get motion sick when I am
travelling, no matter the mode of transportation or the road/environment conditions)

2/6 - Please state your gender

- ○ Male
- ○ Female

- ○ Non-binary / third gender
- ○ Prefer not to say

3/6 - Please state your age

[ ]

MS as a child

The following two questions will ask about your experiences as a child and the last 10 years for the same motion sickness sources

These questions will be used to determine your Motion Sickness Susceptibility using a standardized method (MSSQ-short)

4/6 - As a child (**before age 12**), how often you felt **sick or nauseated** (tick boxes)

	N.A. - Never traveled	Never Felt Sick	Rarely Felt Sick	Sometimes Felt Sick	Frequently Felt Sick
Cars	○	○	○	○	○
Buses or coaches	○	○	○	○	○
Trains	○	○	○	○	○
Aircraft	○	○	○	○	○
Small Boats	○	○	○	○	○
Ships, e.g. Channel ferries	○	○	○	○	○
Swings in playgrounds	○	○	○	○	○

Roundabouts in playgrounds	○	○	○	○	○
Big Dippers, Funfair Rides	○	○	○	○	○

5/6 - **Over the last 10 years**, how often you **felt sick or nauseated** (tick boxes)

	N.A. - Never traveled	Never Felt Sick	Rarely Felt Sick	Sometimes Felt Sick	Frequently Felt Sick
Cars	○	○	○	○	○
Buses or coaches	○	○	○	○	○
Trains	○	○	○	○	○
Aircraft	○	○	○	○	○
Small Boats	○	○	○	○	○
Ships, e.g. Channel ferries	○	○	○	○	○
Swings in playgrounds	○	○	○	○	○
Roundabouts in playgrounds	○	○	○	○	○
Big Dippers, Funfair Rides	○	○	○	○	○

Contact info

6/6 - Please enter your email address (TU Delft email address if possible)
This is used for the contact and experiment scheduling

If you have any questions, please feel from to contact me:

Wouter Spek
W.J.Spek@student.tudelft.nl
<phone number>

Please complete the survey by clicking the arrow

If you have any comments, feel free to leave them here:

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Appendix F

Post Trial Survey

(Graded for the AE4020 Course)

This appendix contains the survey that participants received after the trial. The online survey contains logic that (dis)abled certain questions based on which trial type and/or number they completed. This logic is not visible in this PDF, but can be deduced from the question naming.

General_info

Please write down your Participant number (or ask the researcher)

Which trial did you perform Today?

- Baseline
- Light interface
- Sound and Light interface

Which trial number did you participate in Today?

- The first trial
- The second trial
- The third/last trial

!!!
This survey will ask you to leave subjective textual comments. In order to protect your own privacy, please make sure that your comments do not contain any personal information.
!!!

However, your comments can be very valuable for the output of the research.

per_trial_Q1

The following statements will be about your experience of Today's trial in the SIMONA Research Simulator

---

Please read the statements thoroughly and provide your level of agreement.

	Strongly **dis**agree	Somewhat **dis**agree	Neither **dis**agree nor agree	Somewhat agree	Strongly agree
The ride was comfortable	○	○	○	○	○
I could not focus on my reading task	○	○	○	○	○
The simulator motion felt like an actual car drive	○	○	○	○	○
Having to provide the MISC score regularly distracted me a lot	○	○	○	○	○
I noticed that my torso/neck anticipated on the movements in time	○	○	○	○	○

The following statements will specifically be about the interface (light or sound information) that has been presented during Today's trial.

Please read the statements thoroughly and provide your level of agreement.

	Strongly **dis**agree	Somewhat **dis**agree	Neither **dis**agree nor agree	Somewhat agree	Strongly agree

I saw a clear relation between the motion and the lights/sounds	○	○	○	○	○
The light/sound interface made the drive more comfortable	○	○	○	○	○
I was more aware of the light/sound interface than of the motion	○	○	○	○	○
I trusted the information from the interface to be correct	○	○	○	○	○
I quickly knew how to interpret the light/sound information	○	○	○	○	○
The light/sound interface felt very intrusive	○	○	○	○	○
The timing of the lights/sounds was perfect	○	○	○	○	○

How would you describe the driving behavior of Today's trial?

- ○ Defensive / Cautious driving behavior
- ○ Normal / Neutral driving behavior
- ○ Dynamic / aggressive driving behavior
- ○ Extremely dynamic / Extremely aggressive driving behavior

Symptoms Questionnaire

Please indicate if and/or how you experienced any of the following symptoms during the simulator exposure

	None	Some	Medium	Severe
General discomfort	○	○	○	○
Fatigue	○	○	○	○
Headache	○	○	○	○
Eyestrain	○	○	○	○
Difficulty focusing (eyes)	○	○	○	○
Increased salivation	○	○	○	○
Decreased salivation	○	○	○	○
Sweating	○	○	○	○
Hot flashes / Feeling overheated	○	○	○	○
Cold flashes / Feeling cold	○	○	○	○
Increased heartbeat	○	○	○	○
Nausea	○	○	○	○
Difficulty concentrating	○	○	○	○
Fullness of head	○	○	○	○
Blurred vision	○	○	○	○
Dizziness (eyes open)	○	○	○	○

Dizziness (eyes closed)	○	○	○	○
Vertigo (spinning)	○	○	○	○
Faintness	○	○	○	○
Awareness of breathing	○	○	○	○
Stomach awareness	○	○	○	○
Decreased appetite	○	○	○	○
Increased appetite	○	○	○	○
Burping	○	○	○	○

Please comment here if you had any other symptoms

Per_trail_Q1_counter

The following statements will again be about your experience of Today's trial in the SIMONA Research Simulator.

Please read the statements thoroughly and provide your level of agreement.

	Strongly **dis**agree	Somewhat **dis**agree	Neither **dis**agree nor agree	Somewhat agree	Strongly agree
I had an unpleasant drive	○	○	○	○	○

It was easy for me to concentrate on my reading task	○	○	○	○	○
The movements were not representative of a real life drive	○	○	○	○	○
I did not feel distracted by the need to provide the MISC score	○	○	○	○	○
My torso/neck muscles only had a (later) correcting reaction to the movements	○	○	○	○	○

Please leave a comment about your general experience of the ride

The following questions will again be specifically be about the interface (light or sound information) that has been presented during Today's trial.

Please read the statements thoroughly and provide your level of agreement.

	Strongly **dis**agree	Somewhat **dis**agree	Neither **dis**agree nor agree	Somewhat agree	Strongly agree
The lights/sounds did not seem to be correlated with the movements	○	○	○	○	○

My comfort of the drive was decreased by the light/sound interface	○	○	○	○	○
The motion was more prominent than the light/sound interface	○	○	○	○	○
I was uncertain if the interface was giving consistent and/or correct information	○	○	○	○	○
It took me a long time to understand how to interpret the information from the light/sound interface	○	○	○	○	○
The light/sound interface did not annoy me	○	○	○	○	○
The timing of light/sound information should be earlier or later	○	○	○	○	○

Please describe your experience with Today's interface in one sentence

Full_experiment_comparison

The following statements will be about the full (3 trial) experiment.

Please read the statements thoroughly and provide your level of agreement.

	Strongly **dis**agree	Somewhat **dis**agree	Neither **dis**agree nor agree	Somewhat agree	Strongly agree
I prefer a ride without an interface	○	○	○	○	○
The ride itself felt more comfortable with an interface	○	○	○	○	○
I prefer the light interface over the combined light/sound interface	○	○	○	○	○

You have now experienced all three conditions. The next questions will ask you to compare your experiences with these trials.

Which trial did you consider to be the **most comfortable**?

- ○ No cues, the driving behaviour was comfortable on its own
- ○ The light interface
- ○ The combined sound and light interface

Which trial had the **most extreme** motion / driving behavior?

- ○ The baseline
- ○ The light interface
- ○ The combined sound and light interface
- ○ NA: All trials felt similar in driving behaviour

Which trial had the **least extreme** motion / driving behavior?

- The baseline
- The light interface
- The combined sound and light interface
- NA: All trials felt similar in driving behaviour

Would you personally prefer a light/sound interface in current vehicles?

- No interface as such, they do not improve the driving experience
- The light interface
- The combined sound and light interface
- A sound only based interface (not in this experiment)

If any, which trials felt as if they had identical driving style and simulator motions the entire route?

- All 3 trials had different driving styles and simulation motions.
- The **Baseline** and **Light cue** trial were identical; the combined Light -and Sound cue trial was different.
- The **Baseline** and **Light- and Sound cue** trial were identical; the Light cue trial was different.
- The **Light cue** and **Light- and Sound cue** trial were identical; the Baseline trial was different.
- All 3 trials had identical driving behavior and similar motions.

The following statements will be about the full (3 trial) experiment
---
Please read the statements thoroughly and provide your level of agreement.

	Strongly	Somewhat	Neither disagree	Somewhat	Strongly

	disagree	**dis**agree	nor agree	agree	agree
I would prefer a ride with such an interface	○	○	○	○	○
The interface had a negative effect on the ride comfort	○	○	○	○	○
I prefer the combined light/sound interface over the (only) light interface	○	○	○	○	○

Please describe your preference and/or experiences of the 3 different conditions in a couple of words

Full_experiment_informed

All three experiment trials had **identical simulator motion**.

Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.

○ No cues, the driving behaviour was comfortable on its own
○ The light interface
○ The combined sound and light interface

Thank you very much for participating in this 3-trials experiment!
All experimental output will be anonymously processed and will contribute to

this research field, as well as my MSc thesis.

Information management: It is important not to talk to other (potential) participants about the experiment conditions. Therefore, make sure to limit the information you are sharing in the coming weeks until the end of all experiment trials.

Make sure to get your 10euro Bol.com voucher for Today's participation!

If you have any general comments about the full experiment, please leave them here.

Trial_ending

Thank you very much for participating in this experiment trial. In order to generate useful experimental output, it is important that you participate in all three trials of this experiment. At the end, you will be asked to compare all three experiments trials.

Since participation is completely voluntary, you are always allowed to stop at any time without having to provide a reason. Please let the researcher know if this is the case.

Information management: It is important not to talk to other (potential) participants about the experiment conditions. Therefore, make sure to limit the information you are sharing in the coming weeks until the end of all experiment trials.

Make sure to get your 10euro Bol.com voucher for Today's participation!

If you have any general comments about the experiment trial of Today, please leave them down here.

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Appendix G

Results per Participant

This appendix contains all measured data from each participant except for the head tracking data. This section will describe the formatted layout for each participant. It has been formatted to fit two pages per participant.

Each participant[1] page starts off with its selected criteria (gender; MSSQ-short) after which results from each individual trial are presented in the participated order. The participants' preferred trial (based on the survey) is represented in the title of the trial type. This is directly followed by three MISC representations and their subjectively experienced driving style. Next, the researcher subjectively noted participants' general behavior with respect to the head movements and tablet position, followed by possible comments by the researcher.

Each question block had its question order randomized to avoid the recognition of counter questions and had the option to add a comment for clarification. The tables below start with the same acronyms as the comments do:
Symptoms: additional comment - will be asked every trial.
BSL: Baseline; Sound; Light - will be asked every trial.
LCcue: Light & Sound cues - will not be presented after a baseline trial.
Ending: Overall comment - will be asked when finishing the survey.
Final comparison comment: in addition to the comparison questions.

This will be followed by two graphs that present the raw data of the MISC and experienced symptoms for each trial. The two tables that follow present the result of the survey questions with closed questions on a 5-point Likerts scale (Strongly disagree - Strongly agree).

The fully written questions will only be presented once and numbered according to the participants' result tables. In the actual survey (Appendix F), the questions were split into questions and counter questions with always another type of question (block) in between. Furthermore, within the question blocks, the individual questions were randomized to avoid recognition.

[1] In all calculations, participant 3 is replaced by participant 19

Table G-1: BSL: Likert Questions Each Trial (question/counter-question)

#	Keyword	Question	Counter
1.	Comfort	The ride was comfortable	I had an unpleasant drive
2.	Task focus	I could not focus on my reading task	It was easy for me to concentrate on my reading task
3.	Driving Realism	The simulator motion felt like an actual car drive	The movements were not representative of a real life drive
4.	Distraction MISC	Having to provide the MISC score regularly distracted me a lot	I did not feel distracted by the need to provide the MISC score
5.	Body response	I noticed that my torso/neck anticipated on the movements in time	My torso/neck muscles only had a (later) correcting reaction to the movements

Table G-2: LScue: Interface Trial Likert Questions (question/counter-question)

#	Keyword	Question	Counter Question
1.	Clearness	I saw a clear relation between the motion and the lights/sounds	The lights/sounds did not seem to be correlated with the movements
2.	Comfort	The light/sound interface made the drive more comfortable	My comfort of the drive was decreased by the light/sound interface
3.	Motion vs. Cue	I was more aware of the light/sound interface than of the motion	The motion was more prominent than the light/sound interface
4.	Trust/Correctness	I trusted the information from the interface to be correct	I was uncertain if the interface was giving consistent and/or correct information
5.	Intuitiveness	I quickly knew how to interpret the light/sound information	It took me a long time to understand how to interpret the information from the light/sound interface
6.	Intrusivesness	The light/sound interface felt very intrusive	The light/sound interface did not annoy me
7.	Correct timing	The timing of the lights/sounds was perfect	The timing of light/sound information should be earlier or later

Table G-3: Final comparison: Likert Questions (question/counter-question)

#	Keyword	Question	Counter Question
1.	Preference	I prefer a ride without an interface	I would prefer a ride with such an interface
2.	Comfort	The ride itself felt more comfortable with an interface	The interface had a negative effect on the ride comfort
3.	Combined vs. Light	I prefer the light interface over the combined light/sound interface	I prefer the combined light/sound interface over the (only) light interface

This page is left blank intentionally.

Results Participant 1 (BCL)

This subject is a 19 years old Male with a MSSQ of 6 (32.27 population percentile).

Trial 1: Baseline

MISC: 0.53; 0.8; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: very stable; the tablet placement was: on legs; Comment 1: forget to tell trial types.
Symptoms comment: ∼
BSL comment: "*The ride didn't really feel like a real car but more like a swing of some sort, but it still wans't unconformtable and didn't cause me any special symptoms that I wouldn't experience in a car sometimes*"
Ending comment: "*General experience was pleasant*"

Trial 2: Sound and Light interface

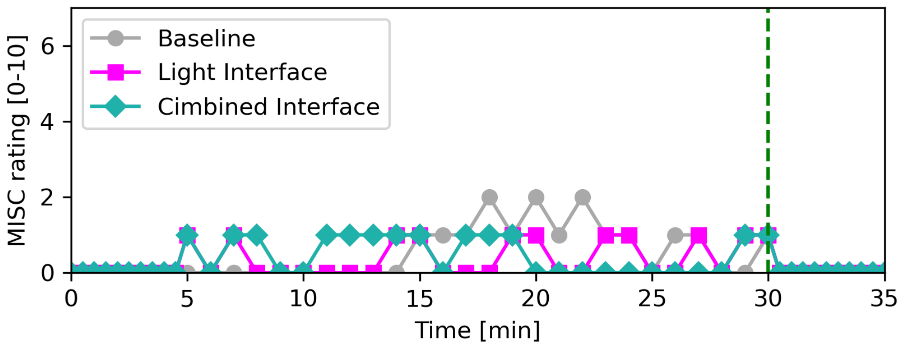
MISC: 0.41; 0.2; 1 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: very stable; the tablet placement was: on legs.
Symptoms comment: ∼
BSL comment: ∼
SLcue comment: "*Relatively pleasant drive which partial mimics the real car motion*"
Ending comment: "*Whole experience is pleasant*"

Trial 3: Light interface (preferred trial)

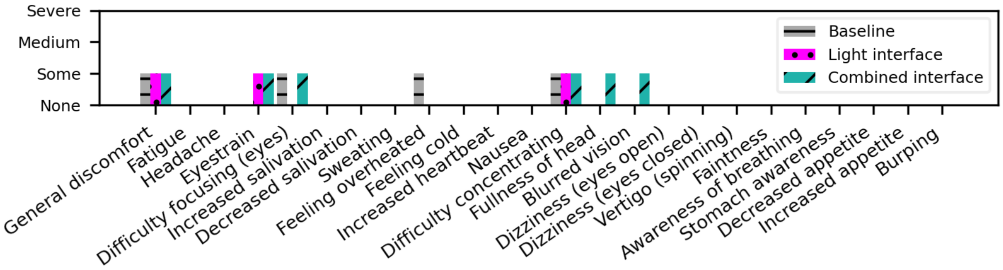
MISC: 0.34; 0.5; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: very stable; the tablet placement was: on legs.
Symptoms comment: ∼
BSL comment: "*Ride felt good, it was the most comfortable out of all three trials, although I don't know if that is because now I got used to the motion of the simulator and knew what to expect*"
SLcue comment: "*Pleasant, most comfortable out of all three experiments*"
Ending comment: ∼

Final Comparison Comment

"*I feel like sound and light made the whole experience feel more like an actual car, although the sounds felt more like some futuristic flying vehicle than the normal car. The most comfortable ride was the one with just light, but as I said I don't know if that was because I got used to the simulator movements and knew what to expect*"



MISC of Participant 1



Symptoms per trial type 1

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	1/-1	2/-2	1/-1	clearness	0/-1	1/-1	prefer interface	-2/1
2.	reading focus	-1/1	-2/2	-1/1	comfort	1/-2	1/-1	improved comfort	2/-2
3.	realistic drive	-1/1	0/0	-1/-1	motion vs. cue	-2/2	0/1	light vs. combined	-1/-1
4.	distraction MISC	-2/2	-2/2	-2/2	trust/correctness	1/-1	1/0		
5.	Body response	1/1	1/-1	1/1	intuitiveness	-1/0	-1/-1		
6.	-				intrusiveness	-1/2	-2/2		
7.	-				correct timing	-1/2	-2/2		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The light interface*"
Which trial had the most extreme motion / driving behavior?	"*The baseline*"
Which trial had the least extreme motion / driving behavior?	"*The light interface*"
Would you personally prefer a light/sound interface in current vehicles?	"*A sound only based interface (not in this experiment)*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*All 3 trials had identical driving behavior and similar motions.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*The light interface*"

Results Participant 2 (CBL)

This subject is a 24 years old Male with a MSSQ of 16 (65.96 population percentile).

Trial 1: Sound and Light interface (preferred trial)

MISC: 1.36; 1.6; 3 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: normal; the tablet placement was: hand/leg; Comment 1: feels as night; Comment 2: amazed about the light cues.
Symptoms comment: "*lack of natural light made me feel a bit sleepy*"
BSL comment: "*reasonably comfortable*"
SLcue comment: "*The ride was pretty comfortable, but because I couldn't really focus on reading I would still prefer to drive by myself..*"
Ending comment: ∼

Trial 2: Baseline

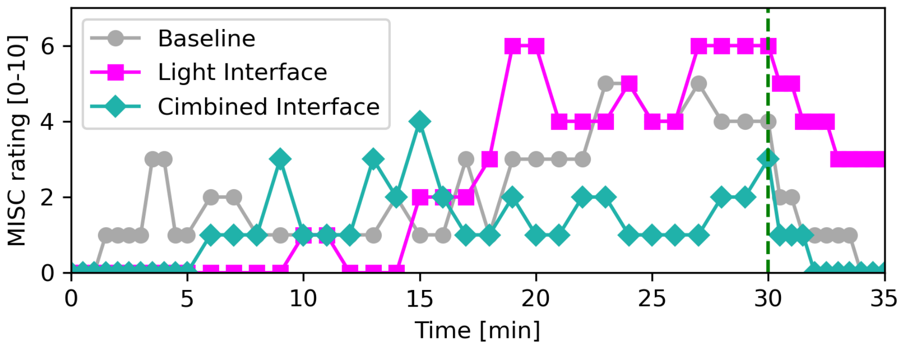
MISC: 2.34; 4.1; 4 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: normal; the tablet placement was: hand/leg; Comment 1: cabin light turned off at 3:00; Comment 2: head against headrest.
Symptoms comment: ∼
BSL comment: "*The ride itself was comfortable, but focussing on reading was not really possible (even without having to provide the misc scores) because of slight nausea*"
Ending comment: ∼

Trial 3: Light interface

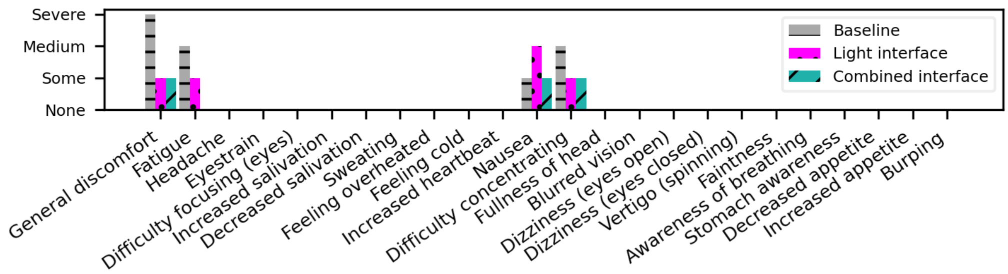
MISC: 2.4; 4.9; 6 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: normal; the tablet placement was: hand/leg; Comment 1: had a bad sleep, was still waking up; Comment 2: headache ; Comment 3: used some paracetamols before; Comment 4: lowered tablet brightness after 10min; Comment 5: 28:00 terminated experiment.
Symptoms comment: ∼
BSL comment: "*the ride was not bad, but the combination with reading made it hard to not get nausea. The lights were intuative but could also be a quite intrusive and distracting.*"
SLcue comment: "*nice ride and read at first, lot of nausea in the second half*"
Ending comment: ∼

Final Comparison Comment

" *I did not notice a large difference in the driving-style during the three sessions. In all, I would prefer the ride without an interface, as it is quite distracting. Maybe the sound-only interface would also be the best option*"



MISC of Participant 2



Symptoms per trial type 2

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	0/-1	-1/1	1/1	clearness	2/-1	2/-2	prefer interface	-1/-1
2.	reading focus	1/-1	2/-2	1/-1	comfort	0/1	1/-2	improved comfort	0/0
3.	realistic drive	0/-1	1/-1	1/0	motion vs. cue	0/0	0/-1	light vs. combined	0/0
4.	distraction MISC	1/-2	1/-1	1/-2	trust/correctness	1/-1	2/-1		
5.	Body response	-1/-1	1/-1	0/-1	intuitiveness	2/-2	1/-1		
6.	-				intrusiveness	1/0	-1/1		
7.	-				correct timing	1/0	-1/1		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The combined sound and light interface*"
Which trial had the most extreme motion / driving behavior?	"*The baseline*"
Which trial had the least extreme motion / driving behavior?	"*The combined sound and light interface*"
Would you personally prefer a light/sound interface in current vehicles?	"*No interface as such, they do not improve the driving experience*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*The Light cue and Light- and Sound cue trial were identical; the Baseline trial was different.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*No cues, the driving behaviour was comfortable on its own*"

Results Participant 3 (LBC) - Drop out subject!

This subject is a 19 years old Female with a MSSQ of 20 (74.83 population percentile).

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Results Participant 4 (BLC)

This subject is a 19 years old Male with a MSSQ of 11 (48.7 population percentile).

Trial 1: Baseline

MISC: 1.37; 2.2; 3 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: on legs.
Symptoms comment: ~
BSL comment: ~
Ending comment: ~

Trial 2: Light interface

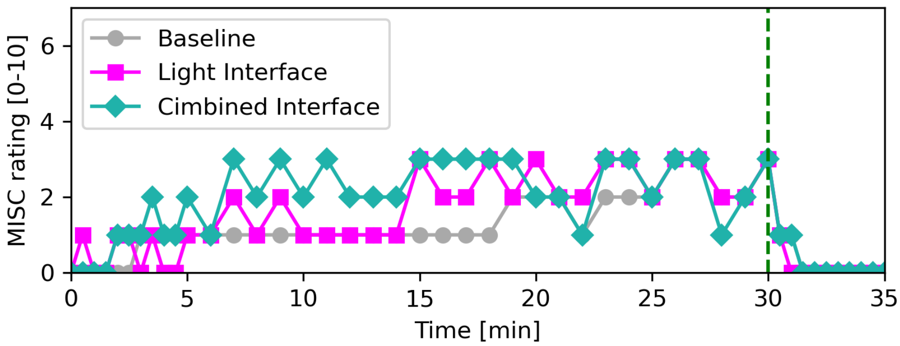
MISC: 1.77; 2.5; 3 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: on legs; Comment 1: Sound sporadically crashed.
Symptoms comment: ~
BSL comment: "*It didn't feel like a real life drive*"
SLcue comment: "*I didn't mind the llights so much*"
Ending comment: "*Sometimes the sound suddenly stopped for a second*"

Trial 3: Sound and Light interface (preferred trial)

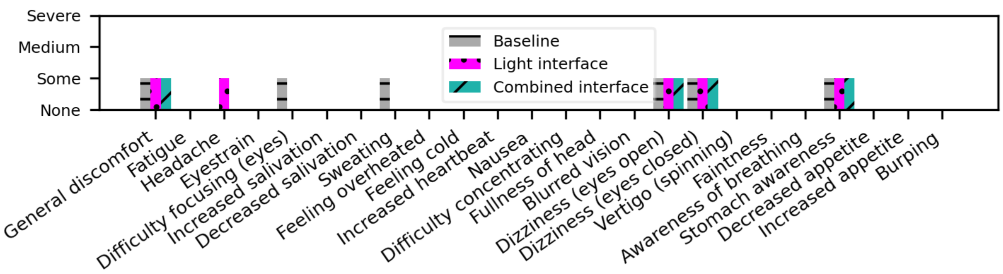
MISC: 2.13; 2.3; 3 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: on legs; Comment 1: most comfortable.
Symptoms comment: ~
BSL comment: "*The ride felt more comfortable than the others*"
SLcue comment: "*The sound made the ride feel more like a real life drive*"
Ending comment: ~

Final Comparison Comment

"*I prefer the light and sound. The baseline and light felt the same*"



MISC of Participant 4



Symptoms per trial type 4

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	1/-1	0/-1	0/-1	clearness	0/0	2/-1	prefer interface	-1/1
2.	reading focus	-2/1	-2/1	-1/1	comfort	-1/-1	1/-1	improved comfort	1/-1
3.	realistic drive	-1/1	-1/1	1/-1	motion vs. cue	-1/2	0/1	light vs. combined	-1/1
4.	distraction MISC	0/-1	0/0	-1/1	trust/correctness	0/0	1/-1		
5.	Body response	1/-1	1/1	1/-1	intuitiveness	-1/1	1/-1		
6.	-				intrusiveness	0/1	-1/1		
7.	-				correct timing	0/1	-1/1		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The combined sound and light interface*"
Which trial had the most extreme motion / driving behavior?	"*The baseline*"
Which trial had the least extreme motion / driving behavior?	"*The combined sound and light interface*"
Would you personally prefer a light/sound interface in current vehicles?	"*The combined sound and light interface*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*The Baseline and Light cue trial were identical; the combined Light -and Sound cue trial was different.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*The combined sound and light interface*"

Results Participant 5 (CLB)

This subject is a 32 years old Male with a MSSQ of 16 (49.22 population percentile).

Trial 1: Sound and Light interface

MISC: 0.13; 0.3; 2 (Avg; last 10min; last point) "*Extremely dynamic / Extremely aggressive driving behavior*"
The head movements were: stable; the tablet placement was: on legs.
Symptoms comment: ∼
BSL comment: "*I was not consistently distracted by the need to provide the MISC score, only occasionally*"
SLcue comment: "*Focussing on reading distracted me from trying very hard to interpret the sounds/lights.*"
Ending comment: ∼

Trial 2: Light interface (preferred trial)

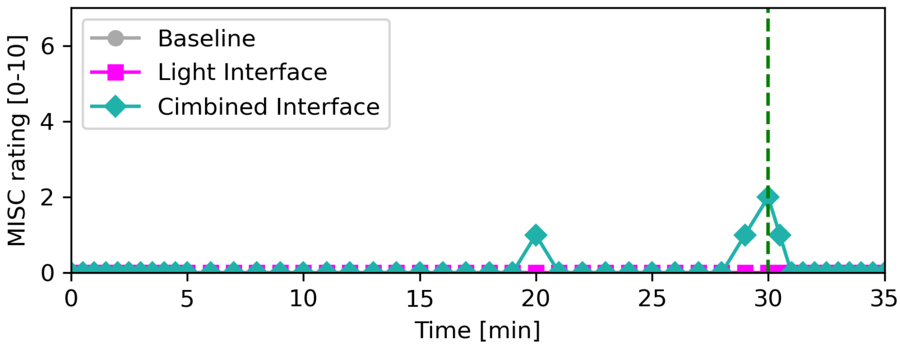
MISC: 0.0; 0.0; 0 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: on legs.
Symptoms comment: ∼
BSL comment: "*I was able to anticipate the movement much better that last time (light/sound trial) but still did not focus on interpreting the light and sound very much*"
SLcue comment: "*I focussed on the movement and reading rather than the light/sound, so I did not have a strong interpretation of its meaning*"
Ending comment: ∼

Trial 3: Baseline

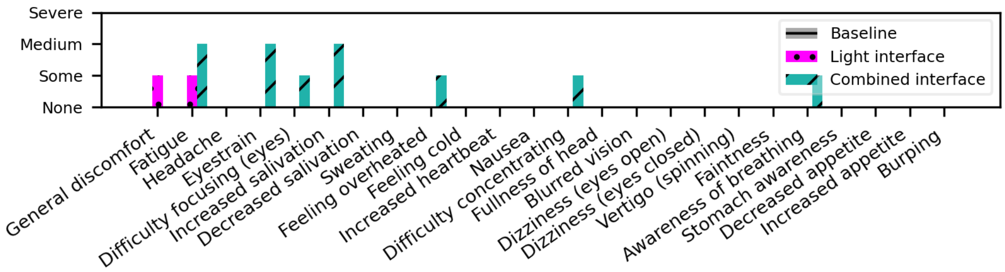
MISC: 0.0; 0.0; 0 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: on legs.
Symptoms comment: ∼
BSL comment: "*Although the ride was not unpleasant, I normally look outside in a car anyway and that makes the ride more pleasant for me*"
Ending comment: ∼

Final Comparison Comment

"*I thought the baseline and light-only interface were very comparable, with a small improvement in comfort with the light-only interface*"



MISC of Participant 5



Symptoms per trial type 5

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	1/0	2/-1	-1/0	clearness	0/-1	1/0	prefer interface	0/0
2.	reading focus	-2/1	-2/1	-1/-1	comfort	0/1	-1/1	improved comfort	0/0
3.	realistic drive	1/0	1/0	-1/1	motion vs. cue	-2/0	-2/1	light vs. combined	2/-2
4.	distraction MISC	0/1	-1/-1	1/-1	trust/correctness	0/0	1/1		
5.	Body response	1/2	1/0	0/1	intuitiveness	-1/2	-1/1		
6.	-				intrusiveness	0/1	0/-1		
7.	-				correct timing	0/1	0/-1		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The light interface*"
Which trial had the most extreme motion / driving behavior?	"*The combined sound and light interface*"
Which trial had the least extreme motion / driving behavior?	"*The light interface*"
Would you personally prefer a light/sound interface in current vehicles?	"*The light interface*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*The Baseline and Light cue trial were identical; the combined Light -and Sound cue trial was different.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*The light interface*"

Results Participant 6 (LCB)

This subject is a 22 years old Female with a MSSQ of 7 (32.88 population percentile).

Trial 1: Light interface

MISC: 2.77; 3.1; 4 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: to chair; the tablet placement was: on legs.
Symptoms comment: ~
BSL comment: "*At the turns the sudden stopping movement after the turn was more disorienting than the actual turn*"
SLcue comment: "*At times the lights seemed very in synch with the movements which helped predict the movement, making it feel less disorienting in general*"
Ending comment: ~

Trial 2: Sound and Light interface (preferred trial)

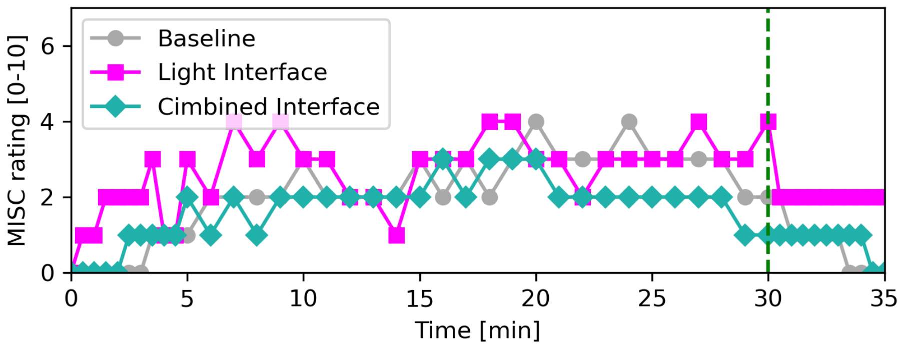
MISC: 1.77; 1.8; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: to chair; the tablet placement was: on legs.
Symptoms comment: ~
BSL comment: "*Although I seemed to notice discrepancies between the light animation and movements during the last session, the noise signals seemed more in synch with the movements of the simulator. So overall I was surprised less often when a turn was sharper than I expected in this session than the last.*"
SLcue comment: "*The ride was much more comfortable, especially the turns, I was surprised less often by sharp ones which were the source of my discomfort during the last session.*"
Ending comment: ~

Trial 3: Baseline

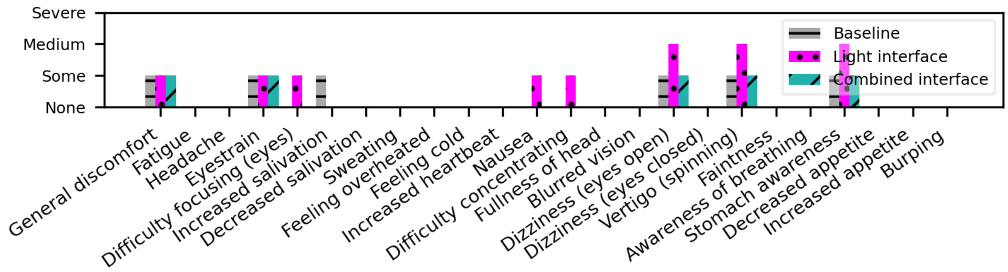
MISC: 2.22; 2.9; 2 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: to chair; the tablet placement was: on legs; Comment 1: right chair missing; Comment 2: just ate; Comment 3: used prepositioning sound for anticipation.
Symptoms comment: ~
BSL comment: "*the movements were a bit more disorienting this time compared to the last trials*"
Ending comment: ~

Final Comparison Comment

"*The sound interface was most comfortable to me, the light interface at times was not helpful when the light movement was not completely synched to the simulator movement, in those cases I would have preferred no interface. For the baseline I noticed I would still pay attention to the simulator sounds to predict when the motion would start.*"



MISC of Participant 6



Symptoms per trial type 6

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	-1/1	1/1	1/-1	clearness	2/-2	2/-2	prefer interface	-1/1
2.	reading focus	-1/1	1/-1	0/0	comfort	1/-2	2/-2	improved comfort	1/1
3.	realistic drive	-1/0	-1/0	-1/1	motion vs. cue	-1/1	-1/0	light vs. combined	-2/2
4.	distraction MISC	-1/0	1/-1	1/-1	trust/correctness	1/1	1/-1		
5.	Body response	-2/-1	-1/1	1/-1	intuitiveness	1/-2	2/-2		
6.	-				intrusiveness	-1/1	-1/1		
7.	-				correct timing	-1/1	-1/1		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	*"The combined sound and light interface"*
Which trial had the most extreme motion / driving behavior?	*"The light interface"*
Which trial had the least extreme motion / driving behavior?	*"The combined sound and light interface"*
Would you personally prefer a light/sound interface in current vehicles?	*"A sound only based interface (not in this experiment)"*
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*The Baseline and Light- and Sound cue trial were identical; the Light cue trial was different."*
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	*"The combined sound and light interface"*

Results Participant 7 (BCL)

This subject is a 24 years old Female with a MSSQ of 14 (58.96 population percentile).

Trial 1: Baseline

MISC: 3.57; 4.8; 7 (Avg; last 10min; last point) "*Defensive / Cautious driving behavior*"
The head movements were: normal; the tablet placement was: hands on legs; Comment 1: bit tired...; Comment 2: value at pling (not highest); Comment 3: 9:00 warm; Comment 4: 7:30 sound crash; Comment 5: hard to concentrate.
Symptoms comment: ∼
BSL comment: "*For me, the ride was better than a normal car drive would have been. However, looking outside normally would prevent me from being sick and I couldn't do that this time.*"
Ending comment: ∼

Trial 2: Sound and Light interface (preferred trial)

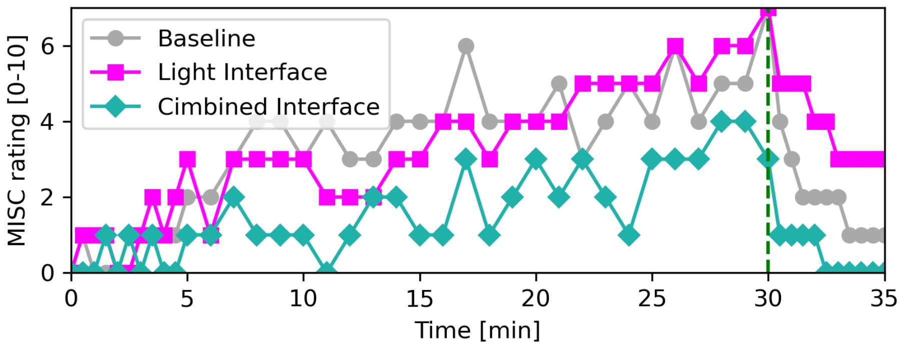
MISC: 1.72; 2.8; 3 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: nromal; the tablet placement was: hands on legs; Comment 1: did not notice sound interface (while present).
Symptoms comment: ∼
BSL comment: "*I felt that it was much better than the previous ride without light and sound. I really noticed my body could anticipate on the movements. After a while I still got a bit more sick in my stomage. I'm not exactly sure why, maybe just because i've been in the simulator for a while or because I was more concentrated on the reading.* "
SLcue comment: "*The light interface really helped me, but I am not sure if the sound interface did something for me since I didn't notice it that much.*"
Ending comment: ∼

Trial 3: Light interface

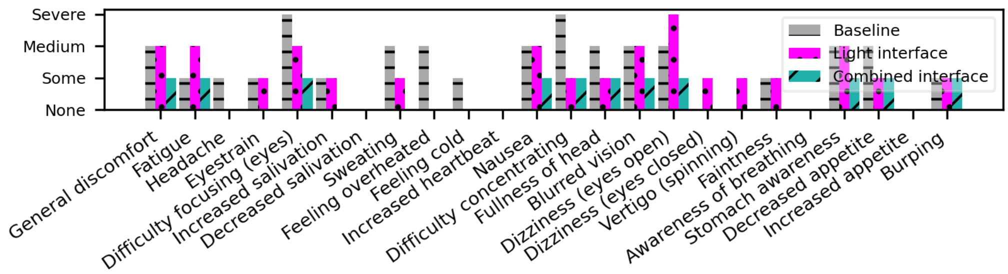
MISC: 3.44; 5.4; 7 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: hands on legs; Comment 1: well rested.
Symptoms comment: "*Pain in my neck/shoulders*"
BSL comment: "*At first it was OK, but it got worse pretty quickly. I think it was the worst ride of the three.* "
SLcue comment: "*I felt like it was sometimes correct, but sometimes not. Then it was not doing anything while the simulator did move. That was quite confusing.* "
Ending comment: ∼

Final Comparison Comment

"*I liked the light/soung interface the best, because I felt like it was the most accurate.* "



MISC of Participant 7



Symptoms per trial type 7

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	-1/1	-2/2	1/0	clearness	-1/1	2/-2	prefer interface	-2/2
2.	reading focus	2/-2	0/-1	1/-1	comfort	-1/0	2/-2	improved comfort	-1/-1
3.	realistic drive	-1/1	0/0	-1/0	motion vs. cue	0/0	-1/-1	light vs. combined	-1/2
4.	distraction MISC	2/-2	-1/0	1/-1	trust/correctness	-2/2	1/-1		
5.	Body response	-1/-2	-1/1	2/-2	intuitiveness	-1/1	1/-1		
6.	-				intrusiveness	-1/-2	-1/0		
7.	-				correct timing	-1/-2	-1/0		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	*"The combined sound and light interface"*
Which trial had the most extreme motion / driving behavior?	*"NA: All trials felt similar in driving behaviour"*
Which trial had the least extreme motion / driving behavior?	*"NA: All trials felt similar in driving behaviour"*
Would you personally prefer a light/sound interface in current vehicles?	*"The combined sound and light interface"*
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*All 3 trials had identical driving behavior and similar motions."*
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	*"The combined sound and light interface"*

Results Participant 8 (CBL)

This subject is a 23 years old Male with a MSSQ of 18 (70.26 population percentile).

Trial 1: Sound and Light interface

MISC: 0.49; 0.7; 2 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: stable; the tablet placement was: on legs; Comment 1: pretty comfortable; Comment 2: piloting experience.
Symptoms comment: ∼
BSL comment: "*Level of comfort definetly could be improved as it felt that the driving was too dynamic (sharp and fast turns), but I wouldn't describe it as uncomfortable either.*"
SLcue comment: "*I felt like the sounds helped interpret the accelerations and therfore allowed me to anticipate and thus improved the comfort of the ride. I didn't really payed attention to the lights but I somehow feel like they improved comfort a little bit.*"
Ending comment: ∼

Trial 2: Baseline

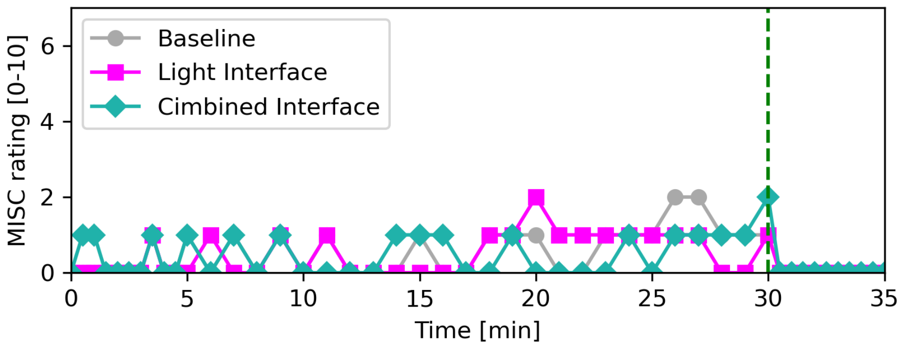
MISC: 0.59; 1.0; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: normal; the tablet placement was: on legs .
Symptoms comment: ∼
BSL comment: "*The fact that there was no sound or light interface made the ride feel much more calm and "slow" that with the sound and light interface where it felt really dynamic. Apart from what felt like a few agressive turns, it was overall relatively comfortable.*"
Ending comment: "*One the one hand, as stated, the ride felt more calm than with the light and sound, but on the other hand I felt like the discomfort from the turns acumulated faster during this ride, which lead to a small peak in discomfort where I started getting stomach awarness.* "

Trial 3: Light interface (preferred trial)

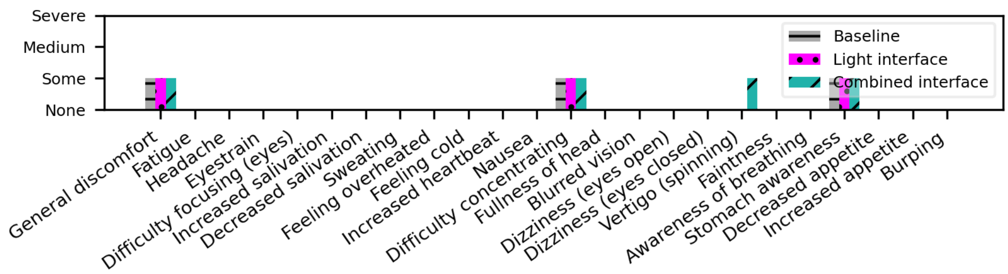
MISC: 0.51; 0.8; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: normal; the tablet placement was: on legs; Comment 1: started wrong file, restarted after a minute.
Symptoms comment: ∼
BSL comment: "*The ride felt more agressive than the baseline, but alos much more conservative than the light/sound interface, although they were probably the same program.*"
SLcue comment: "*At first I didnt pay attention to the lights, but when I looked at them for a few seconds I understood how they worked and I feel that from this point onwards it helped me anticipate the movements.*"
Ending comment: ∼

Final Comparison Comment

"*While both the light and sound helped me anticipate the movements, I think that the sound made the ride feel more intense than it was. Overall, I still think a combination of both light and sound is the most optimal solution, but both would have to be tuned. A relatively quiet engine-like sound would help anticipate the accelerations and decelerations. The light interface can help with that aswell, but also help anticipate the turns. However, I feel like the given light interface was a bit too flashy and distracting. Therefore, a combination of both tuned down light and sound would feel optimal for me.*"



MISC of Participant 8



Symptoms per trial type 8

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	1/-1	1/-1	1/-2	clearness	2/-2	2/-2	prefer interface	-2/1
2.	reading focus	-1/1	-1/1	-1/1	comfort	1/-1	2/-2	improved comfort	2/-2
3.	realistic drive	1/-1	2/-1	1/-1	motion vs. cue	-1/1	-2/2	light vs. combined	1/-1
4.	distraction MISC	1/-1	1/-1	1/-1	trust/correctness	2/-2	1/-1		
5.	Body response	0/1	1/-1	0/0	intuitiveness	1/-1	1/-1		
6.	-				intrusiveness	-2/2	-2/2		
7.	-				correct timing	-2/2	-2/2		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The light interface*"
Which trial had the most extreme motion / driving behavior?	"*The combined sound and light interface*"
Which trial had the least extreme motion / driving behavior?	"*The baseline*"
Would you personally prefer a light/sound interface in current vehicles?	"*The light interface*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*All 3 trials had different driving styles and simulation motions.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*The light interface*"

Results Participant 9 (LBC)

This subject is a 26 years old Female with a MSSQ of 26 (83.81 population percentile).

Trial 1: Light interface (preferred trial)

MISC: 3.10; 3.3; 4 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: in hands; Comment 1: tense, exited for the experiment.
Symptoms comment: "*Feeling of tightness in chest*"
BSL comment: "*Overall good*"
SLcue comment: "*Lights seemed to have made the experience more pleasant, could not focus entirely on reading, but overall discomfort was not great.*"
Ending comment: ∼

Trial 2: Baseline

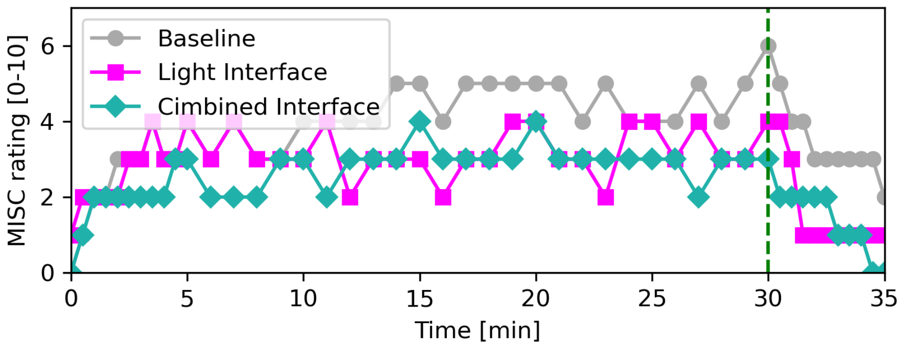
MISC: 4.05; 4.6; 6 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: in hands.
Symptoms comment: ∼
BSL comment: "*Felt dizzy and faint for a period that started towards the middle of the experiment (roughly) and persisted and hampered concentration. This was accompanied by slight headache and nausea towards the end.*"
Ending comment: ∼

Trial 3: Sound and Light interface

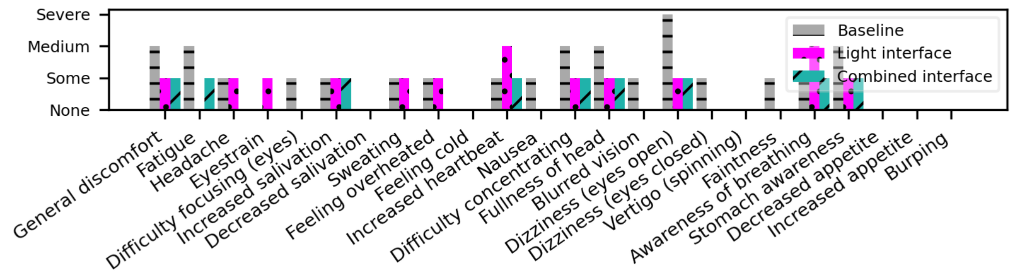
MISC: 2.71; 2.9; 3 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: in hands; Comment 1: 9:30 long cue crash; Comment 2: 14:30 looked around.
Symptoms comment: ∼
BSL comment: "*Good overall, significantly better than last trial. Worst symptoms manifested as dizziness / slight drowsiness.*"
SLcue comment: "*I felt that the light interface contributed to a significant improvement in how I experienced the ride (perhaps also worth mentioning that I went into this last trial with this conviction from the first trial). I was not very sure about the contribution of the sound interface.*"
Ending comment: ∼

Final Comparison Comment

"*The light interface seemed to make the ride more enjoyable and was comforting. As for the sound interface, it felt mildly annoying at some points. Of the three conditions, I would prefer having the light interface on its own the most.*"



MISC of Participant 9



Symptoms per trial type 9

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	-1/1	1/-1	1/-1	clearness	0/-1	1/-1	prefer interface	-1/1
2.	reading focus	1/-1	0/0	-1/1	comfort	1/-1	1/-1	improved comfort	1/-1
3.	realistic drive	1/-1	1/-1	1/-1	motion vs. cue	-1/1	0/-1	light vs. combined	1/-1
4.	distraction MISC	0/0	0/-1	-1/1	trust/correctness	0/0	1/-1		
5.	Body response	0/0	0/-1	0/0	intuitiveness	0/-1	1/-1		
6.	-				intrusiveness	-1/1	-1/1		
7.	-				correct timing	-1/1	-1/1		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The light interface*"
Which trial had the most extreme motion / driving behavior?	"*The baseline*"
Which trial had the least extreme motion / driving behavior?	"*The combined sound and light interface*"
Would you personally prefer a light/sound interface in current vehicles?	"*The light interface*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*The Light cue and Light- and Sound cue trial were identical; the Baseline trial was different.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*The light interface*"

Results Participant 10 (BLC)

This subject is a 23 years old Male with a MSSQ of 6 (31.05 population percentile).

Trial 1: Baseline

MISC: 1.00; 1.5; 2 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: active/down; the tablet placement was: in hands; Comment 1: felt like driving in the mountains.
Symptoms comment: ~
BSL comment: ~
Ending comment: ~

Trial 2: Light interface

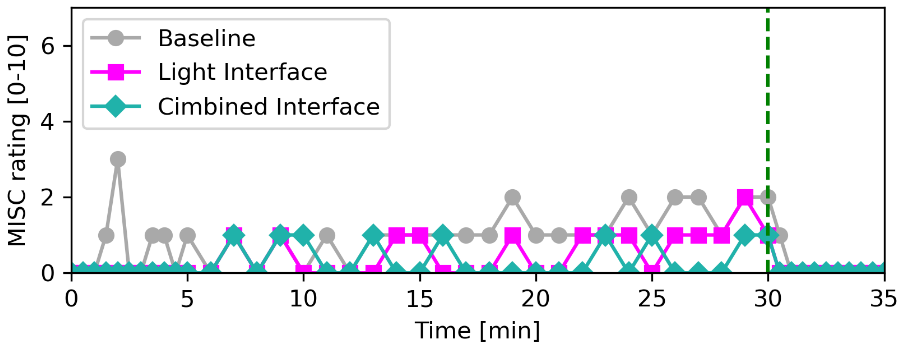
MISC: 0.46; 0.9; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: active/down; the tablet placement was: in hands; Comment 1: distracted; Comment 2: notices pre-positioning.
Symptoms comment: "*Not perfectly rested and alcohol use within last 24 hours fully explains increased salivation*"
BSL comment: "*It was much easier to feel where you were going with the lights. Though, sometimes it felt there were no lights connected to a movement which made it more uneasy since you start 'trusting' the lights*"
SLcue comment: "*A fine session in a motion simulator to catch up on the latest news.*"
Ending comment: "*The lights did take away your focus briefly from reading, especially in the beginning.*"

Trial 3: Sound and Light interface (preferred trial)

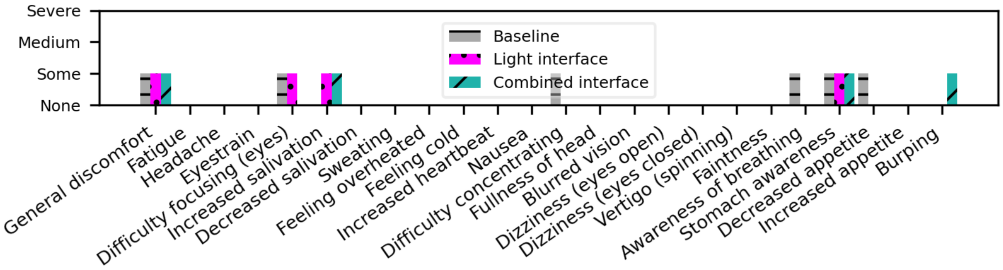
MISC: 0.3; 0.4; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: active/down; the tablet placement was: in hands.
Symptoms comment: "*Just before the experiment I did have a big lunch, which explains the burping*"
BSL comment: "*It felt the easiest of all three rides. I have gotten used to the motions in the simulator*"
SLcue comment: "*I felt the lights played a much larger role in connecting the motion to a direct than the sounds*"
Ending comment: ~

Final Comparison Comment

"*I feel like every trial had identical driving behavior but it was more difficult anticipating the motion in the baseline. Especially in the beginning the light trial could be distracting while trying to focus on reading but after a while it has gotten easier to focus.*"



MISC of Participant 10



Symptoms per trial type 10

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	0/-1	1/-1	1/-1	clearness	1/1	1/-2	prefer interface	-2/2
2.	reading focus	-2/2	-1/1	-2/1	comfort	1/-1	1/-2	improved comfort	2/-1
3.	realistic drive	1/-1	1/-1	1/-1	motion vs. cue	-1/1	1/1	light vs. combined	1/0
4.	distraction MISC	0/0	-1/1	0/0	trust/correctness	1/1	2/-2		
5.	Body response	0/1	-1/1	1/1	intuitiveness	1/-1	2/-1		
6.	-				intrusiveness	-1/0	-1/1		
7.	-				correct timing	-1/0	-1/1		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The combined sound and light interface*"
Which trial had the most extreme motion / driving behavior?	"*NA: All trials felt similar in driving behaviour*"
Which trial had the least extreme motion / driving behavior?	"*NA: All trials felt similar in driving behaviour*"
Would you personally prefer a light/sound interface in current vehicles?	"*The light interface*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*All 3 trials had identical driving behavior and similar motions.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*The combined sound and light interface*"

Results Participant 11 (CLB)

This subject is a 26 years old Female with a MSSQ of 6 (28.56 population percentile).

Trial 1: Sound and Light interface (preferred trial)

MISC: 1.69; 3.1; 4 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: normal; the tablet placement was: on legs; Comment 1: yawning; Comment 2: 24:00 cold; Comment 3: 29:00 cue crash.
Symptoms comment: ∼
BSL comment: "*Sleepy*"
SLcue comment: "*Having the constant projector screen made the ride less relatable but overall comfortable.*"
Ending comment: ∼

Trial 2: Light interface

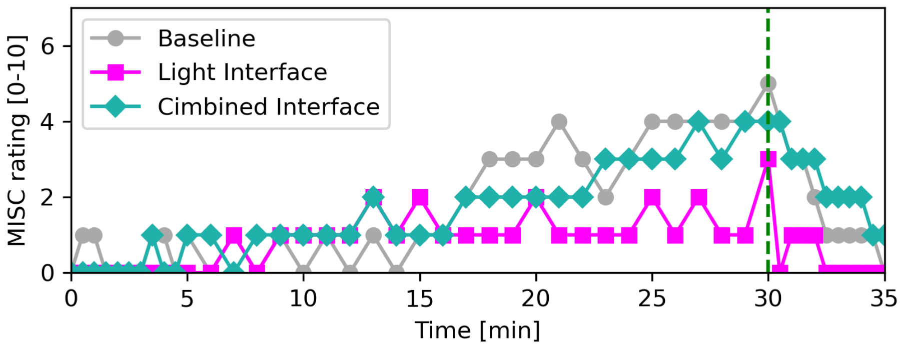
MISC: 1.0; 1.4; 3 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: on legs; Comment 1: singing.
Symptoms comment: ∼
BSL comment: "*Since I expected the motion trajectories, it is now easier to cope with the ride*"
SLcue comment: "*Maybe it is also the topic of my readings, prior information, and my general disposition today, but that felt easy.*"
Ending comment: "*Yay trial 2 done*"

Trial 3: Baseline

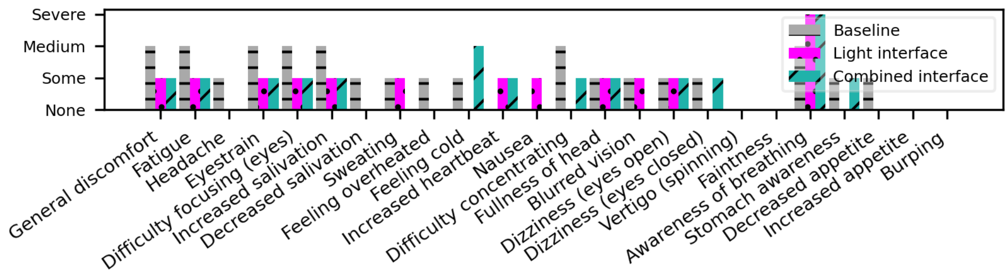
MISC: 1.87; 3.7; 5 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: active; the tablet placement was: on legs/in hands; Comment 1: no right chair; Comment 2: painkiller; Comment 3: "I think this trial is biased".
Symptoms comment: ∼
BSL comment: ∼
Ending comment: ∼

Final Comparison Comment

"*it seems that the combined interface was the most comfortable setup but maybe i have the bias that it was the first one not really sure*"



MISC of Participant 11



Symptoms per trial type 11

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	-1/0	0/-1	1/-1	clearness	2/-1	1/-1	prefer interface	-1/1
2.	reading focus	-1/1	-2/2	0/1	comfort	1/2	-1/1	improved comfort	1/1
3.	realistic drive	2/-1	0/1	-1/-1	motion vs. cue	-1/1	1/0	light vs. combined	-2/1
4.	distraction MISC	1/-1	-2/0	-1/-1	trust/correctness	2/-1	1/-1		
5.	Body response	1/1	2/1	0/1	intuitiveness	2/-1	-1/0		
6.	-				intrusiveness	-1/1	-1/1		
7.	-				correct timing	-1/1	-1/1		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The combined sound and light interface*"
Which trial had the most extreme motion / driving behavior?	"*The light interface*"
Which trial had the least extreme motion / driving behavior?	"*The baseline*"
Would you personally prefer a light/sound interface in current vehicles?	"*The combined sound and light interface*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*All 3 trials had different driving styles and simulation motions.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*The combined sound and light interface*"

Results Participant 12 (LCB)

This subject is a 22 years old Male with a MSSQ of 7 (72.64 population percentile).

Trial 1: Light interface

MISC: 0.35; 0.2; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: on legs.
Symptoms comment: ∼
BSL comment: "*Generally pleasant, most of the discomfort are when I experience deceleration.*"
SLcue comment: "*The lighting interface was new to me and very interesting* "
Ending comment: ∼

Trial 2: Sound and Light interface (preferred trial)

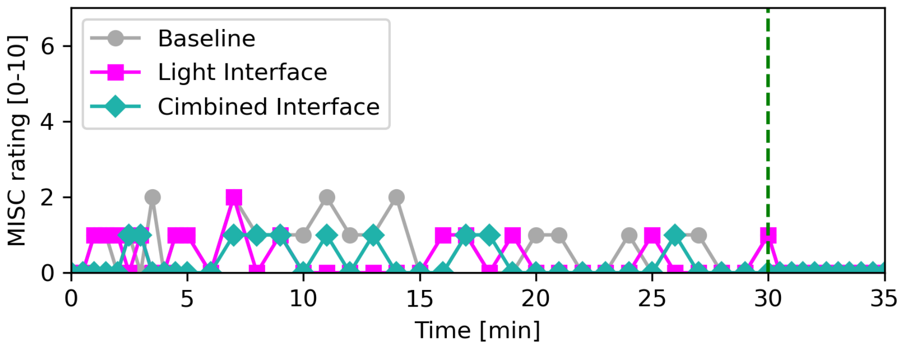
MISC: 0.29; 0.1; 0 (Avg; last 10min; last point) "*Defensive / Cautious driving behavior*"
The head movements were: stable; the tablet placement was: on legs; Comment 1: more tired then T1.
Symptoms comment: ∼
BSL comment: "*It was generally good, however, the sound was a bit too loud, hence it because distracting a just a little bit irritating* "
SLcue comment: "*I like the addition of the sound interface, it helps me to anticipate when I want to close and rest my eyes*"
Ending comment: ∼

Trial 3: Baseline

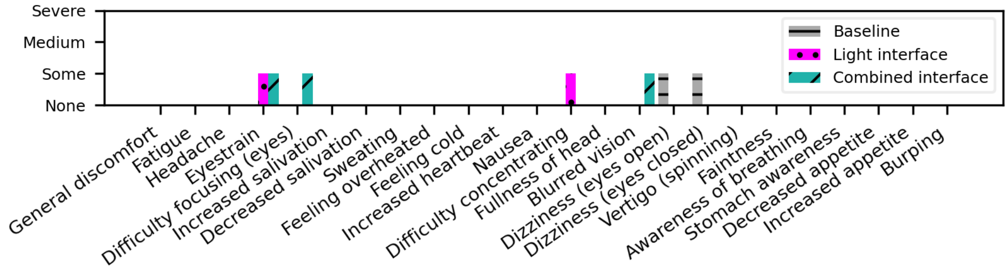
MISC: 0.70; 0.5; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: on legs; Comment 1: better condition than T2.
Symptoms comment: ∼
BSL comment: ∼
Ending comment: ∼

Final Comparison Comment

"*baseline trail doesn't give me any anticipation, light trail gives infomation for my neck to anticipate the motion, while sound/light combined trail gives info for my neck to anticipate even when i close my eyes*"



MISC of Participant 12



Symptoms per trial type 12

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	0/-1	2/-2	2/-2	clearness	2/-2	2/-2	prefer interface	-2/2
2.	reading focus	-1/0	-1/1	-2/0	comfort	1/-1	1/0	improved comfort	2/-2
3.	realistic drive	1/-1	0/-1	2/-2	motion vs. cue	0/-1	-1/0	light vs. combined	-1/1
4.	distraction MISC	1/-1	1/-1	0/-1	trust/correctness	2/-2	1/1		
5.	Body response	0/0	1/1	2/-1	intuitiveness	2/-2	2/-2		
6.	-				intrusiveness	1/1	0/-1		
7.	-				correct timing	1/1	0/-1		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	*"The combined sound and light interface"*
Which trial had the most extreme motion / driving behavior?	*"NA: All trials felt similar in driving behaviour"*
Which trial had the least extreme motion / driving behavior?	*"NA: All trials felt similar in driving behaviour"*
Would you personally prefer a light/sound interface in current vehicles?	*"The combined sound and light interface"*
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*The Baseline and Light cue trial were identical; the combined Light -and Sound cue trial was different."*
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	*"The combined sound and light interface"*

Results Participant 13 (BCL)

This subject is a 26 years old Female with a MSSQ of 7 (72.11 population percentile).

Trial 1: Baseline

MISC: 2.5; 3.5; 4 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: to headrest; the tablet placement was: in hands.
Symptoms comment: ~
BSL comment: ~
Ending comment: ~

Trial 2: Sound and Light interface (preferred trial)

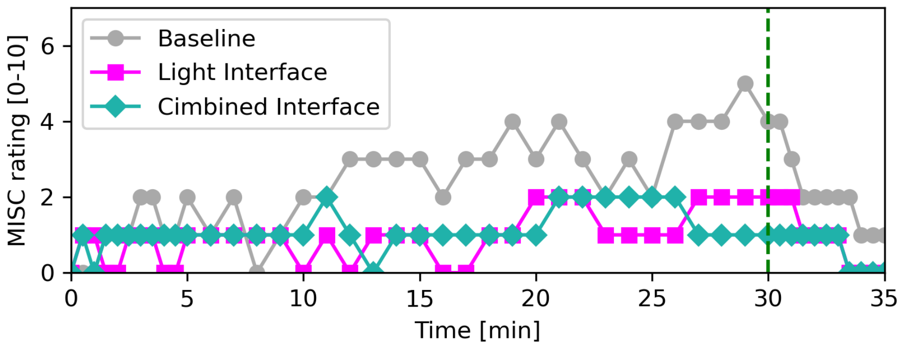
MISC: 1.16; 1.6; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: to headrest; the tablet placement was: in hands; Comment 1: 21:00 cue crash.
Symptoms comment: ~
BSL comment: "*somewhat unrealistic, lights strained my eyes and distract me from the reading task*"
SLcue comment: "*distracting and tiring, comfortable in the first part, but straining in the long run*"
Ending comment: ~

Trial 3: Light interface

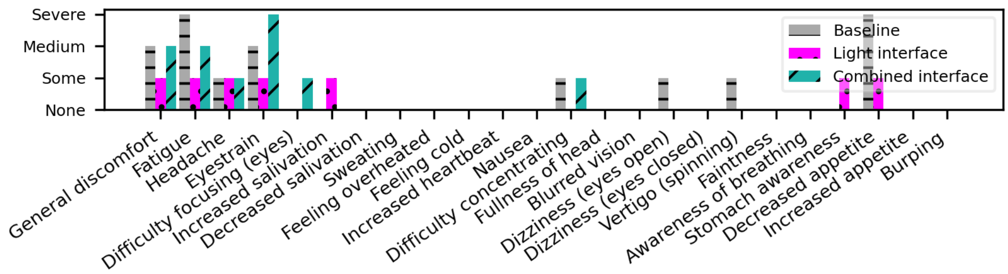
MISC: 1.02; 1.6; 2 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: in hands; Comment 1: interesting articles.
Symptoms comment: ~
BSL comment: "*uncomfortable towards the end, but otherwise fine*"
SLcue comment: "*a bit intrusive, eye straining*"
Ending comment: ~

Final Comparison Comment

"*the baseline gave me more headache, but the light and sound/light only were more straining and distracting. i think i didnt perceive much difference between the light and sound and the light only in terms of sickness, but sound made the ride more realistic*"



MISC of Participant 13



Symptoms per trial type 13

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	-1/1	-1/1	-1/0	clearness	2/-1	1/-2	prefer interface	-1/0
2.	reading focus	-1/0	-2/0	0/0	comfort	0/1	-1/1	improved comfort	1/-1
3.	realistic drive	-2/2	-2/2	-2/1	motion vs. cue	-2/-1	0/-1	light vs. combined	-1/1
4.	distraction MISC	-1/0	-1/1	1/-1	trust/correctness	1/1	2/-2		
5.	Body response	-2/0	0/0	0/0	intuitiveness	1/-2	2/-1		
6.	-				intrusiveness	0/-1	2/-2		
7.	-				correct timing	0/-1	2/-2		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The combined sound and light interface*"
Which trial had the most extreme motion / driving behavior?	"*The baseline*"
Which trial had the least extreme motion / driving behavior?	"*The combined sound and light interface*"
Would you personally prefer a light/sound interface in current vehicles?	"*No interface as such, they do not improve the driving experience*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*The Light cue and Light- and Sound cue trial were identical; the Baseline trial was different.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*The combined sound and light interface*"

Results Participant 14 (CBL)

This subject is a 22 years old Male with a MSSQ of 6 (62.04 population percentile).

Trial 1: Sound and Light interface

MISC: 0.8; 1.0; 1 (Avg; last 10min; last point) "*Defensive / Cautious driving behavior*"
The head movements were: active; the tablet placement was: on legs; Comment 1: moving a lot/legs not comfortable.
Symptoms comment: "*Seat slightly not comfortable (because of the lower seatbelt)*"
BSL comment: "*It was a nice, cautious drive - as I felt it, it took place on a relatively flat ground, without any road irregularities or too tight corners. The braking motion took place comfortably, so did the turning and the acceleration motion.*"
SLcue comment: "*Gave a good and interesting insight about how riding an autonomous vehicle might be (I have never been in one before).*"
Ending comment: "*As a person who likes driving, the experiment made me reflect on how the future might look like, in which self-driving cars could become usual to ride. I asked myself how ready I am to give up driving a car by myself and putting myself into the hands of the intelligent system.*"

Trial 2: Baseline

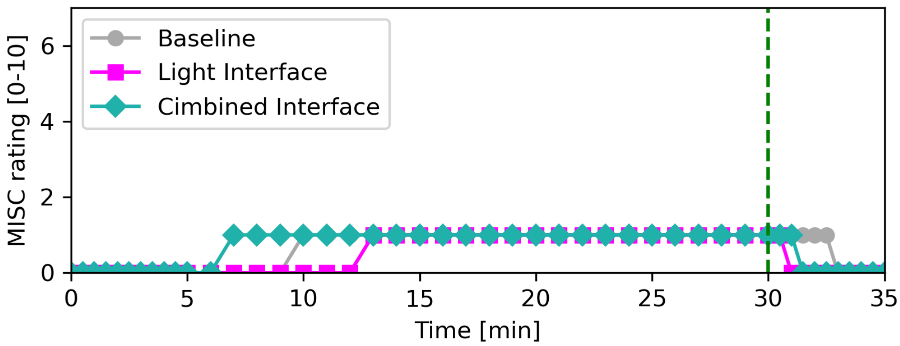
MISC: 0.7; 1.0; 1 (Avg; last 10min; last point) "*Defensive / Cautious driving behavior*"
The head movements were: active; the tablet placement was: on legs; Comment 1: chair vertical stuck.
Symptoms comment: ~
BSL comment: "*I found the drive to be good, just as it was last time. This time it was interesting to experience it only with the baseline motor sound which somehow gave me the impression of a thermal engine powered car, rather than a (fully) electric one.*"
Ending comment: ~

Trial 3: Light interface (preferred trial)

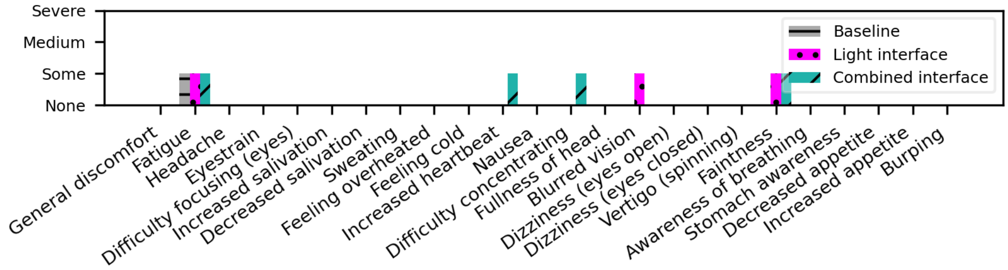
MISC: 0.6; 1.0; 1 (Avg; last 10min; last point) "*Defensive / Cautious driving behavior*"
The head movements were: active; the tablet placement was: on legs; Comment 1: interesting article; Comment 2: more used to the motion.
Symptoms comment: ~
BSL comment: "*Comfortable, cautious drive - I had the impression that the car was driving rather slowly (around 30-40 kmh)*"
SLcue comment: "*It was a pleasant, relaxed drive, as I felt it.*"
Ending comment: ~

Final Comparison Comment

"*I found it easier to focus on the reading task with either one of the cues - only visual or only baseline sound. I didn't feel very distracted by any of the trials, but if I were to choose one in which I was distracted the most, it was the light + sound combination.*"



MISC of Participant 14



Symptoms per trial type 14

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	2/-2	2/-2	2/-2	clearness	2/-1	1/-2	prefer interface	1/-1
2.	reading focus	-1/1	-2/2	-1/1	comfort	0/-2	0/-2	improved comfort	-1/0
3.	realistic drive	2/-1	2/-2	1/-1	motion vs. cue	-1/1	-1/-1	light vs. combined	0/-1
4.	distraction MISC	-1/-1	-1/-1	-1/1	trust/correctness	2/0	2/-2		
5.	Body response	2/-1	2/-1	1/0	intuitiveness	1/-1	0/-2		
6.	-				intrusiveness	-2/2	-2/2		
7.	-				correct timing	-2/2	-2/2		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The light interface*"
Which trial had the most extreme motion / driving behavior?	"*The combined sound and light interface*"
Which trial had the least extreme motion / driving behavior?	"*The light interface*"
Would you personally prefer a light/sound interface in current vehicles?	"*A sound only based interface (not in this experiment)*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*The Baseline and Light cue trial were identical; the combined Light -and Sound cue trial was different.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*The light interface*"

Results Participant 15 (LBC)

This subject is a 25 years old Male with a MSSQ of 7 (32.88 population percentile).

Trial 1: Light interface

MISC: 0.91; 1.2; 1 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: stable; the tablet placement was: hands on legs; Comment 1: excited; Comment 2: no right chair.
Symptoms comment: "*Over stimulated by the motion, lights and newspaper.* "
BSL comment: "*Movements in directions that I was not expecting in a car.*"
SLcue comment: "*The light were overstimulating me. It was harder to focus on the newspaper.* "
Ending comment: "*Good luck.*"

Trial 2: Baseline (preferred trial)

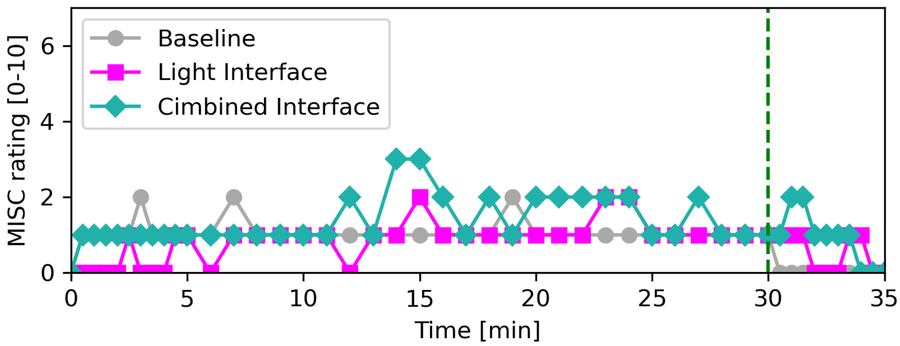
MISC: 1.06; 1.0; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: hands on legs.
Symptoms comment: "*None*"
BSL comment: "*Enjoyable ride, I was able to read the articles in detail*"
Ending comment: "*Thanks, and good luck*"

Trial 3: Sound and Light interface

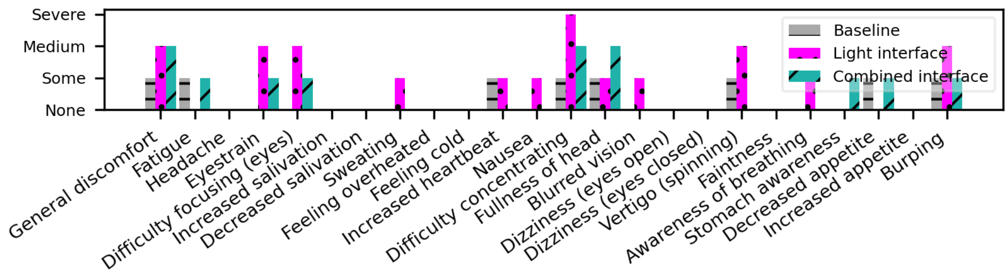
MISC: 1.41; 1.5; 1 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: stable; the tablet placement was: hands on legs; Comment 1: 7:30 no internet; Comment 2: 29:00 distractions of small fly; Comment 3: trouble concentrating.
Symptoms comment: "*In gerenal uncomfortable*"
BSL comment: "*Intense with the lights, sound was more neutral but the background engine sound was the same and not representive what happened with the motion*"
SLcue comment: "*The background engine sounds didn't correlate the motion, the bracking sound and acceleration sounds did.*"
Ending comment: ∼

Final Comparison Comment

"*The light were distracting. If i have a choise I would maybe go with the sound only.* "



MISC of Participant 15



Symptoms per trial type 15

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	1/0	0/0	0/1	clearness	2/-2	2/1	prefer interface	2/-1
2.	reading focus	0/0	2/-2	0/-2	comfort	-2/1	-1/2	improved comfort	-2/1
3.	realistic drive	-1/1	-1/1	1/-1	motion vs. cue	1/-1	1/-1	light vs. combined	-1/-1
4.	distraction MISC	0/0	1/-2	1/-1	trust/correctness	1/1	2/-2		
5.	Body response	1/1	1/1	1/1	intuitiveness	-1/1	1/0		
6.	-				intrusiveness	-1/-2	1/-1		
7.	-				correct timing	-1/-2	1/-1		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	*"No cues, the driving behaviour was comfortable on its own"*
Which trial had the most extreme motion / driving behavior?	*"The combined sound and light interface"*
Which trial had the least extreme motion / driving behavior?	*"The baseline"*
Would you personally prefer a light/sound interface in current vehicles?	*"No interface as such, they do not improve the driving experience"*
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*All 3 trials had identical driving behavior and similar motions."*
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	*"No cues, the driving behaviour was comfortable on its own"*

Results Participant 16 (BLC)

This subject is a 22 years old Female with a MSSQ of 26 (84.31 population percentile).

Trial 1: Baseline

MISC: 1.2; 2.4; 2 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: hands on legs; Comment 1: missing right chair; Comment 2: 20:00 brightness lowered.
Symptoms comment: ∼
BSL comment: ∼
Ending comment: ∼

Trial 2: Light interface (preferred trial)

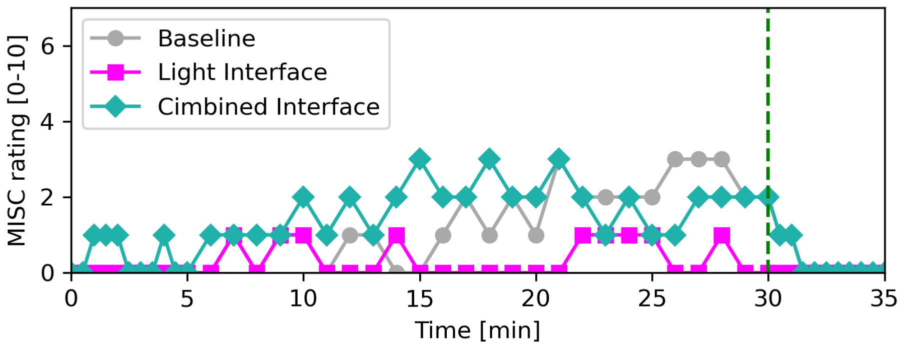
MISC: 0.3; 0.5; 0 (Avg; last 10min; last point) "*Defensive / Cautious driving behavior*"
The head movements were: stable; the tablet placement was: hands on legs.
Symptoms comment: ∼
BSL comment: ∼
SLcue comment: "*It was fine, I don't think the lights made much of a difference.*"
Ending comment: ∼

Trial 3: Sound and Light interface

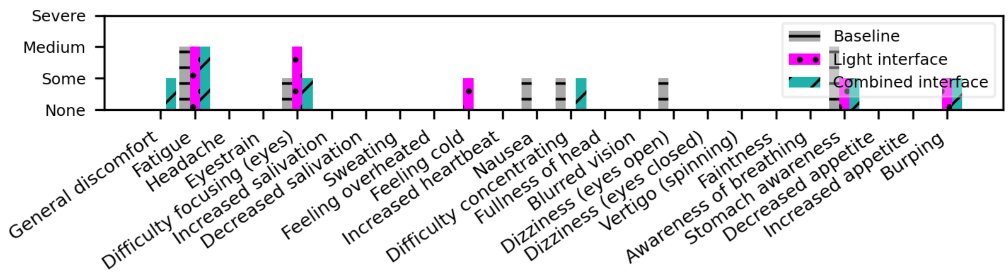
MISC: 1.52; 1.8; 2 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: stable; the tablet placement was: hands on legs; Comment 1: more realistic than last trial.
Symptoms comment: ∼
BSL comment: "*It felt like more of a real drive than previous times*"
SLcue comment: "*Interface made it feel like more of a drive*"
Ending comment: ∼

Final Comparison Comment

"*The light/sound gives you more the idea of a drive, which makes your body react to it properly.*"



MISC of Participant 16



Symptoms per trial type 16

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	1/-2	2/-2	1/-1	clearness	0/-1	1/-2	prefer interface	-2/2
2.	reading focus	-1/-1	-2/2	-1/-1	comfort	1/-2	2/-1	improved comfort	2/-1
3.	realistic drive	0/1	1/0	2/-2	motion vs. cue	0/1	2/-2	light vs. combined	-2/2
4.	distraction MISC	1/-1	-1/2	1/-1	trust/correctness	2/0	2/-2		
5.	Body response	-2/0	-2/0	-2/0	intuitiveness	-1/1	1/-1		
6.	-				intrusiveness	-1/2	-2/2		
7.	-				correct timing	-1/2	-2/2		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The light interface*"
Which trial had the most extreme motion / driving behavior?	"*The combined sound and light interface*"
Which trial had the least extreme motion / driving behavior?	"*The light interface*"
Would you personally prefer a light/sound interface in current vehicles?	"*The combined sound and light interface*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*All 3 trials had different driving styles and simulation motions.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*No cues, the driving behaviour was comfortable on its own*"

Results Participant 17 (CLB)

This subject is a 22 years old Female with a MSSQ of 4 (19.53 population percentile).

Trial 1: Sound and Light interface

MISC: 1.26; 2.1; 2 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: stable; the tablet placement was: in hands; Comment 1: left eye annoyed; dry eyes of screen brightness.
Symptoms comment: ~
BSL comment: "*It was fine. My eyes became a bit dry from the light of the screen.* "
SLcue comment: "*The light interface was sometimes a bit flashy which took my eyes to adjust to the screen again.* "
Ending comment: ~

Trial 2: Light interface (preferred trial)

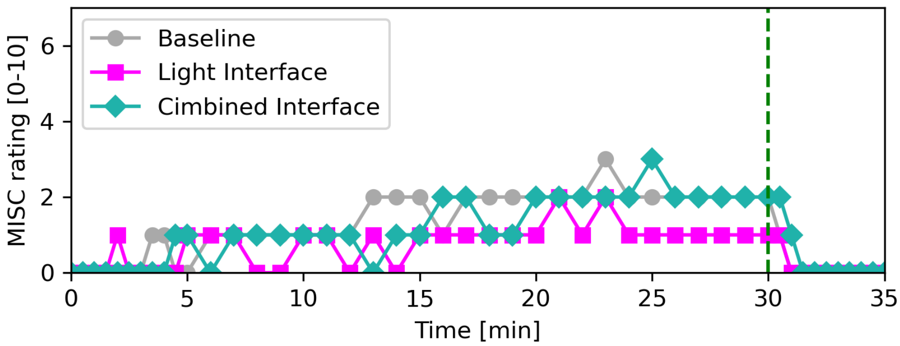
MISC: 0.79; 1.2; 1 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: stable; the tablet placement was: in hands; Comment 1: 23:00 headband annoying; Comment 2: 28:00 dry eyes.
Symptoms comment: ~
BSL comment: "*I experienced sounds from the pumps as well, which felt similar to the sounds of the interface of my previous session.* "
SLcue comment: ~
Ending comment: "*During the trial I experienced dry eyes and a bit of an itch under the headband (this was commented during the trial).* "

Trial 3: Baseline

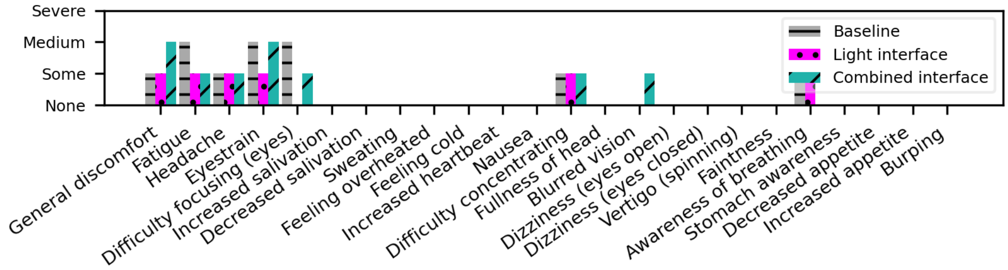
MISC: 1.46; 2.1; 2 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: on legs; Comment 1: had little sleep; Comment 2: 10:30 eyes dry; Comment 3: 23:00 eyes dry.
Symptoms comment: "*I did not have a good night of sleep, so I started out a bit tired.* "
BSL comment: ~
Ending comment: ~

Final Comparison Comment

"*The light sound interface felt a bit much, making it harder to focus on the reading task.* "



MISC of Participant 17



Symptoms per trial type 17

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	1/-1	1/-1	2/-1	clearness	2/-2	2/-2	prefer interface	0/1
2.	reading focus	-1/1	-1/0	-1/1	comfort	1/-1	1/-1	improved comfort	0/-1
3.	realistic drive	1/-1	2/-2	1/-2	motion vs. cue	1/-1	1/-2	light vs. combined	1/-1
4.	distraction MISC	0/0	0/-1	1/-1	trust/correctness	2/-2	0/-2		
5.	Body response	1/-1	1/0	0/-1	intuitiveness	1/-2	1/-2		
6.	-				intrusiveness	1/-1	0/-1		
7.	-				correct timing	1/-1	0/-1		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The light interface*"
Which trial had the most extreme motion / driving behavior?	"*The light interface*"
Which trial had the least extreme motion / driving behavior?	"*The baseline*"
Would you personally prefer a light/sound interface in current vehicles?	"*No interface as such, they do not improve the driving experience*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*All 3 trials had different driving styles and simulation motions.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*No cues, the driving behaviour was comfortable on its own*"

Results Participant 18 (LCB)

This subject is a 22 years old Female with a MSSQ of 8 (39.08 population percentile).

Trial 1: Light interface

MISC: 1.11; 1.2; 1 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: normal/down; the tablet placement was: hands on legs.
Symptoms comment: ∼
BSL comment: "*generally pleasant, right temaperature, only minimal motion discomfort during the mid part*"
SLcue comment: " *slightly distracting sound, felt a bit unreal, like an old motor almost*"
Ending comment: ∼

Trial 2: Sound and Light interface (preferred trial)

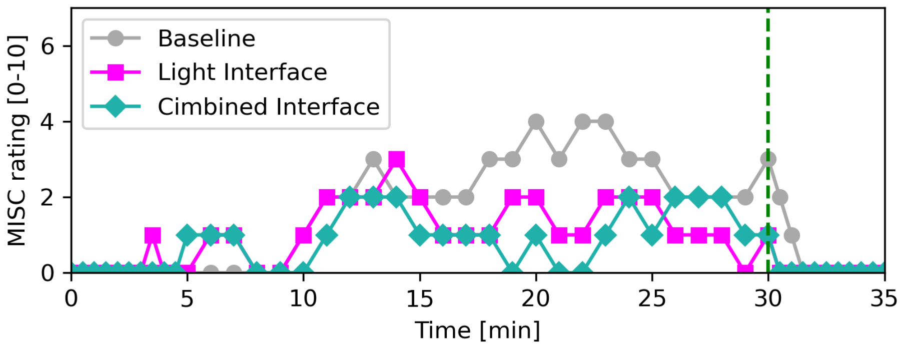
MISC: 0.88; 1.2; 1 (Avg; last 10min; last point) "*Defensive / Cautious driving behavior*"
The head movements were: stable/down; the tablet placement was: hands on legs.
Symptoms comment: ∼
BSL comment: "*much milder than the previous one*"
SLcue comment: "*the sound interface made the movement even more predictible*"
Ending comment: ∼

Trial 3: Baseline

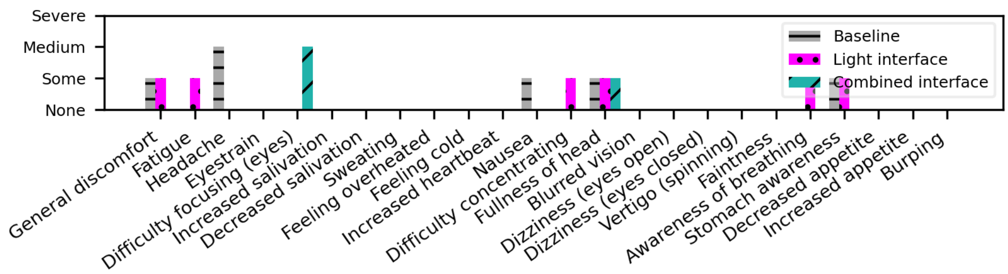
MISC: 1.80; 2.8; 3 (Avg; last 10min; last point) "*Normal / Neutral driving behavior*"
The head movements were: stable; the tablet placement was: hands on legs.
Symptoms comment: ∼
BSL comment: ∼
Ending comment: ∼

Final Comparison Comment

"*after trying the baseline ride, the light and sound interface in comparison feels much more comfortable in movement anticipation*"



MISC of Participant 18



Symptoms per trial type 18

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	0/-2	1/-2	2/-2	clearness	2/-2	2/-2	prefer interface	-2/-2
2.	reading focus	-2/2	-1/2	-2/2	comfort	-1/1	1/-2	improved comfort	2/-1
3.	realistic drive	1/-2	-1/1	2/-2	motion vs. cue	1/-1	0/1	light vs. combined	-1/2
4.	distraction MISC	-2/2	1/-1	-2/2	trust/correctness	2/-2	2/-2		
5.	Body response	-2/1	1/-1	1/-2	intuitiveness	2/-2	2/-2		
6.	-				intrusiveness	1/-1	-2/2		
7.	-				correct timing	1/-1	-2/2		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	"*The combined sound and light interface*"
Which trial had the most extreme motion / driving behavior?	"*The light interface*"
Which trial had the least extreme motion / driving behavior?	"*The combined sound and light interface*"
Would you personally prefer a light/sound interface in current vehicles?	"*The combined sound and light interface*"
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*The Baseline and Light- and Sound cue trial were identical; the Light cue trial was different.*"
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	"*The combined sound and light interface*"

Results Participant 19 (LBC)

This subject is a 21 years old Female with a MSSQ of 15 (63.59 population percentile).

Trial 1: Light interface

MISC: 4.28; 5.1; 6 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: normal/down; the tablet placement was: on legs; Comment 1: 17:00 MISC decrease less during straights.
Symptoms comment: "*stomache contraptions*"
BSL comment: "*In the beginning the uncomfortable feeling went away on the straight parts, but later on not anymore and the uncomfortability build up.*"
SLcue comment: "*I didnt linked the light with the motion, the lights didnt disturb me either*"
Ending comment: ∼

Trial 2: Baseline (preferred trial)

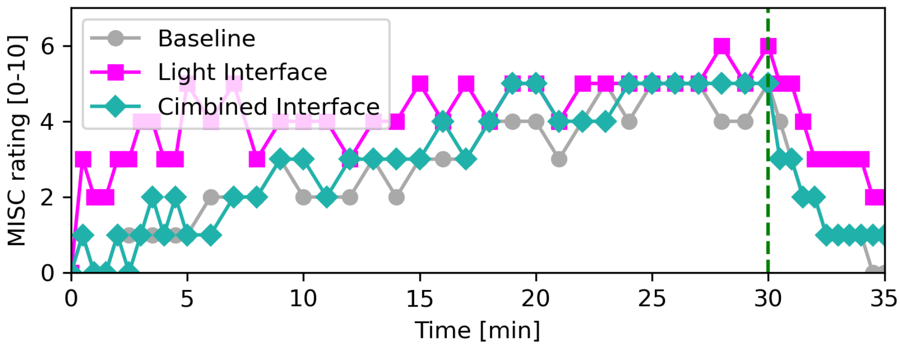
MISC: 2.95; 4.4; 5 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: normal/down; the tablet placement was: hands on legs/on steer; Comment 1: time went faster than last T1; Comment 2: more neckpain than T1.
Symptoms comment: "*from the middle of the experiment my neck was hurting* "
BSL comment: "*it didnt seem to be during half a hour*"
Ending comment: ∼

Trial 3: Sound and Light interface

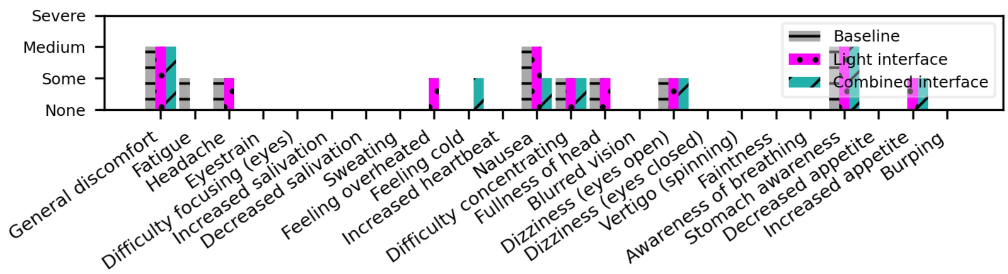
MISC: 3.23; 4.7; 5 (Avg; last 10min; last point) "*Dynamic / aggressive driving behavior*"
The head movements were: stable; the tablet placement was: hands on legs; Comment 1: 9:20 too cold, airco off.
Symptoms comment: ∼
BSL comment: ∼
SLcue comment: "*I found the lights disturbing it felt they were going the wrong way and that made the ride not comfortable it made me a little dizzy. The sound made the ride more comforable because it helped me feeling i was going left and right and not going up and down.* "
Ending comment: ∼

Final Comparison Comment

"*The first experience with the light interface was the most oncomfortable, it also was the one which felt it took more than 30 minutes. The second one, with no interface, was quit comfortable, most of the time, in between the movement the uncomfortable feelings went away. The experience with light and sound was more comfortable than the first one but less comfortable than the second one because the lights made me think i was going the other way than it felt, that made me feel uncomfortable, the sound made it more comfortable because it didnt feel i was going up and down.*"



MISC of Participant 19



Symptoms per trial type 19

Anwsers to Likert Questions (question/counter-question; Table J-1, G-2 & J-3)

#	Question	Motion			Question	Interface		Question	Full
	keyword	B	L	C	keyword	L	C	keyword	Trial 3
1.	comfort	0/0	0/1	0/-1	clearness	-1/0	0/0	prefer interface	1/0
2.	reading focus	-1/1	-1/1	-2/2	comfort	0/0	0/0	improved comfort	1/0
3.	realistic drive	-1/1	0/0	-1/1	motion vs. cue	1/1	0/1	light vs. combined	-2/1
4.	distraction MISC	-2/2	-2/2	-2/2	trust/correctness	1/0	0/-1		
5.	Body response	2/1	1/1	2/1	intuitiveness	-2/2	-1/1		
6.	-				intrusiveness	-2/2	0/0		
7.	-				correct timing	-2/2	0/0		

Closed Questions Trial Comparison

Question	Answer
Which trial did you consider to be the most comfortable?	*"No cues, the driving behaviour was comfortable on its own"*
Which trial had the most extreme motion / driving behavior?	*"The light interface"*
Which trial had the least extreme motion / driving behavior?	*"The baseline"*
Would you personally prefer a light/sound interface in current vehicles?	*"A sound only based interface (not in this experiment)"*
If any, which trials felt as if they had identical driving style and simulator motions the entire route?	*The Baseline and Light- and Sound cue trial were identical; the Light cue trial was different."*
All three experiment trials had identical simulator motion. Does this change your opinion on which trial had the most comfortable ride? Please select your most comfortable ride.	*"No cues, the driving behaviour was comfortable on its own"*

Appendix H

Misery Scale Results

The Motion Sickness response on the MISC scale can be presented in many ways. Starting with all data combined bundled per trial type.

The three plots that follow split these bundled sets into the order in which participants experienced the trials.

These are followed by plots that present the individual total average MISC difference compared to the Baseline trial. For both a full trial average and an average over the last 10 minutes of each trial. A positive value indicates a lower MISC (average) value than the Baseline.

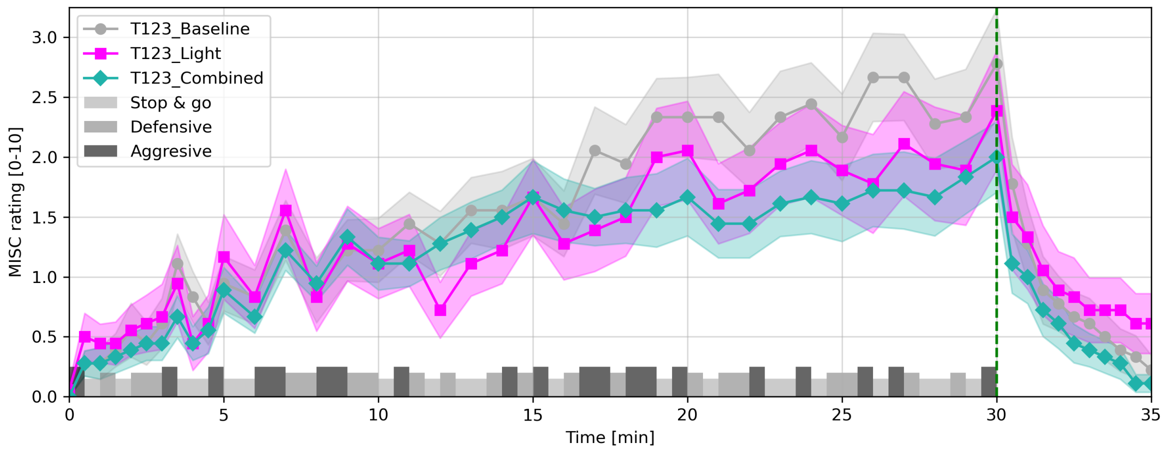


Figure H-1: Combined MISC Results

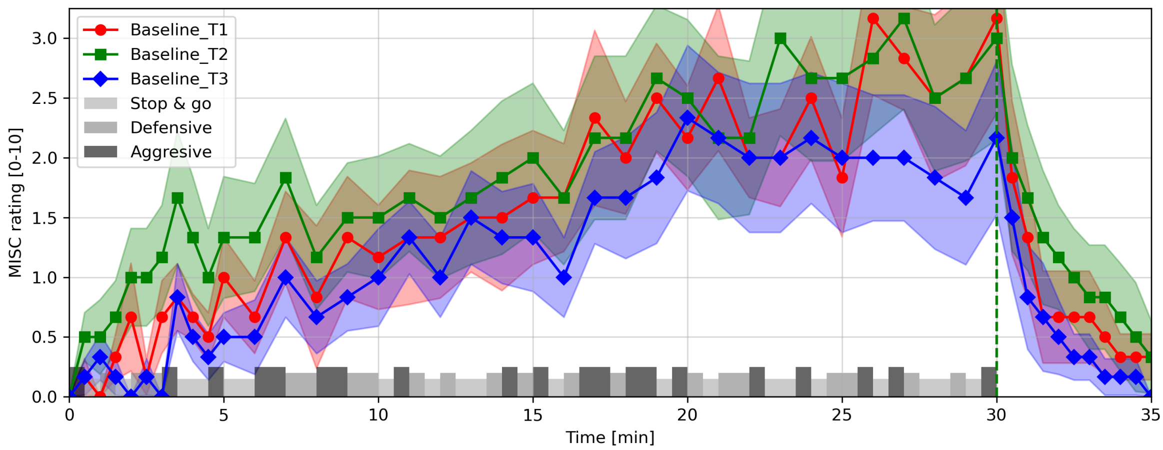


Figure H-2: Baseline only MISC results per Trial

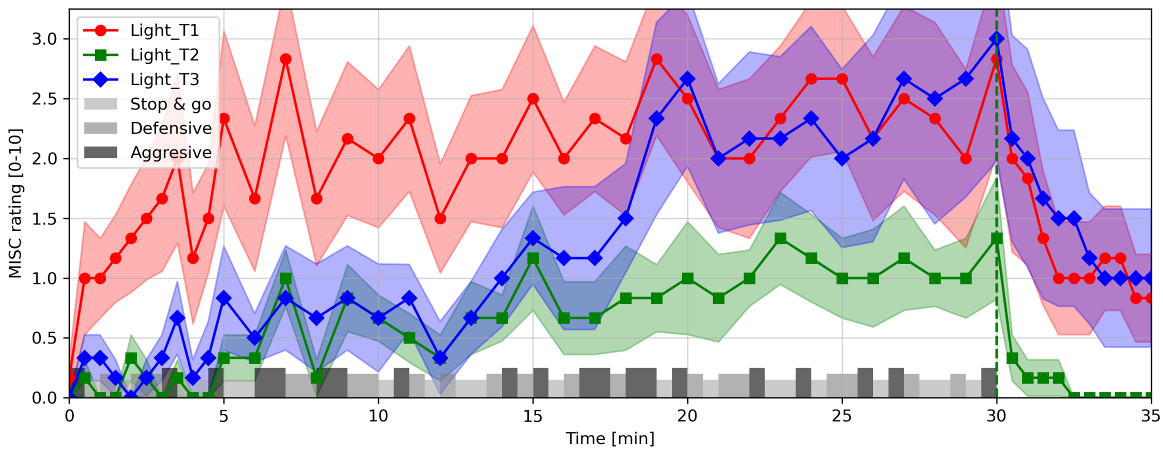


Figure H-3: Light Trial only MISC results per Trial

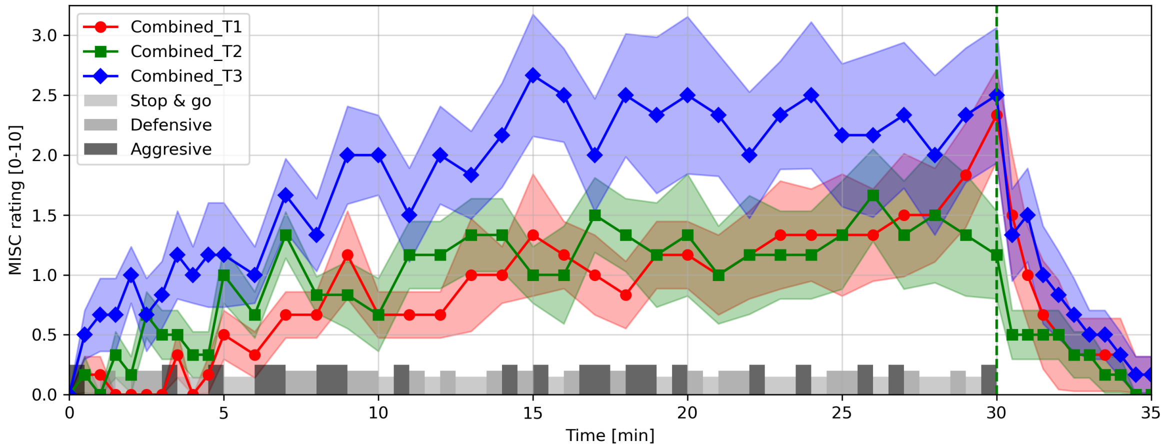


Figure H-4: Combined only MISC results per Trial

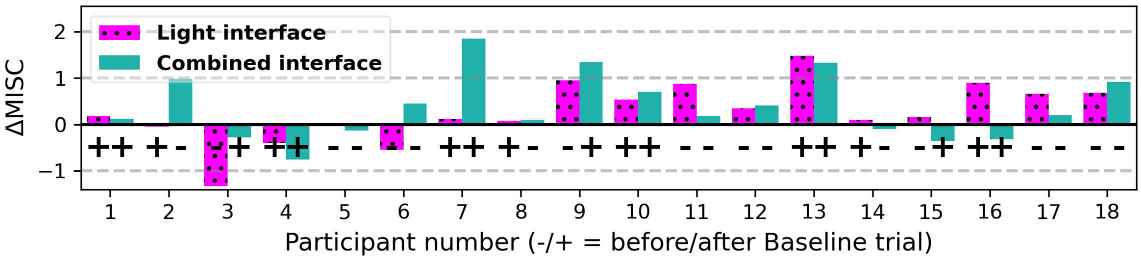


Figure H-5: Average MISC Compared to Baseline

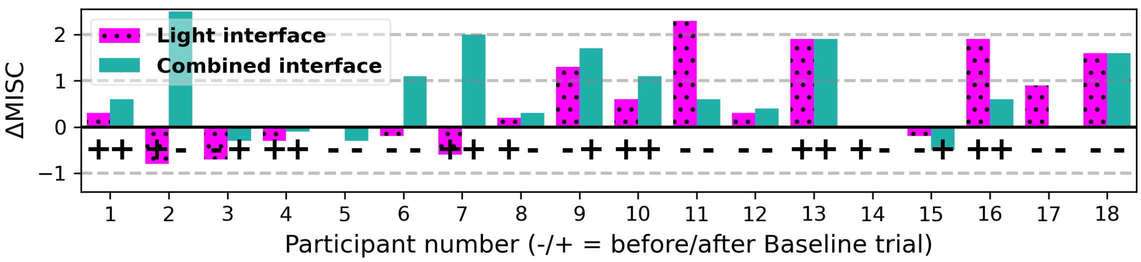


Figure H-6: Average MISC Compared to the Baseline Trial (of the Last 10 Minutes Only)

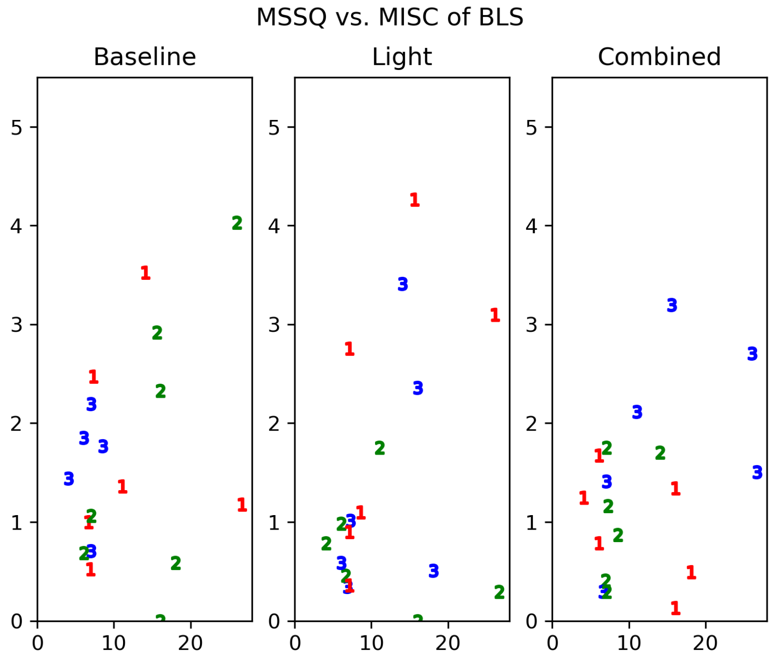


Figure H-7: MISC vs. MSSQ-short Sorted per Trial Type

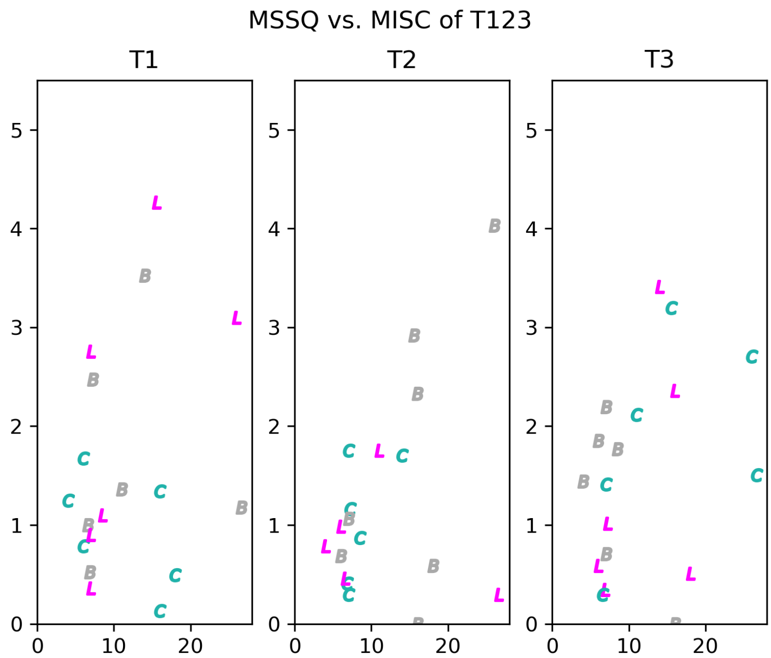


Figure H-8: MISC vs. MSSQ-short Sorted per Trial Number

Appendix I

Motion Sickness Symptom Results

The two following plots represent the symptoms in the order of questions (see Appendix F). In the two different plots, they are bundled per trial type and trial order.

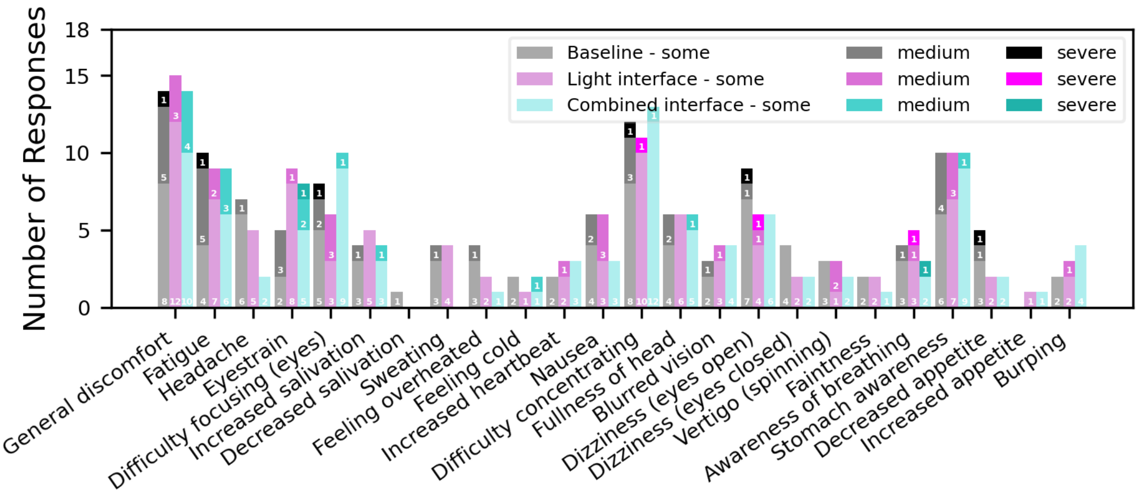


Figure I-1: All Symptoms on Ordinal Scale per Trial Type

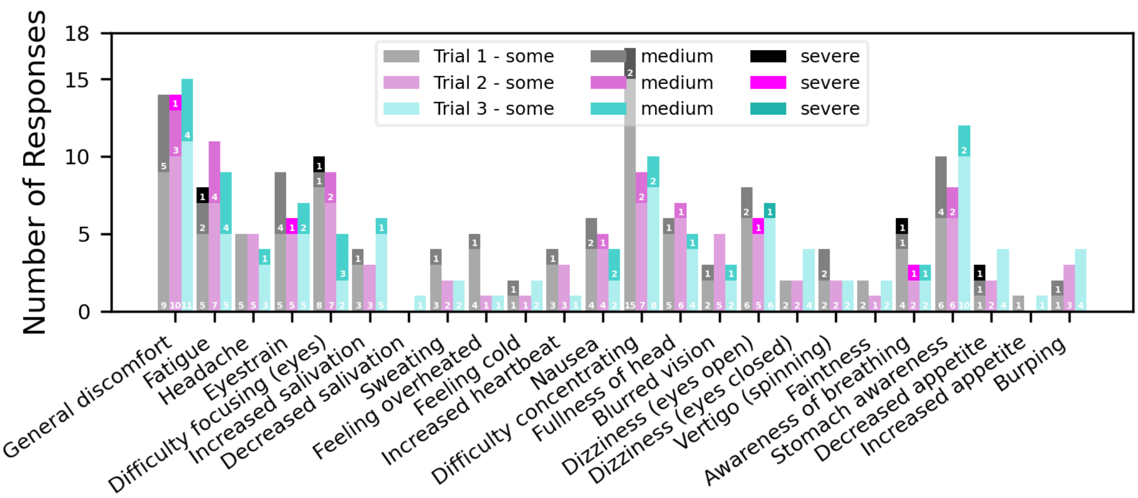


Figure I-2: All Symptoms on Ordinal Scale per Trial Order

Appendix J

Survey Results

This appendix includes the reaction of all Likert questions bundled per trial type. The questions from the survey as in Appendix F are (redundantly) added with the corresponding question numbers.

Table J-1: Likert Questions Each Trial

Keyword	Survey Questions
Comfort	Q1: The ride was comfortable C1: I had an unpleasant drive
Task Focus	Q2: I could not focus on my reading task C2: It was easy for me to concentrate on my reading task
Drive Realism	Q3: The simulator motion felt like an actual car drive C3: The movements were not representative of a real life drive
MISC Distraction	Q4: Having to provide the MISC score regularly distracted me a lot C4: I did not feel distracted by the need to provide the MISC score
Body Response	Q5: I noticed that my torso/neck anticipated on the movements in time C5: My torso/neck muscles only had a (later) correcting reaction to the movements

Table J-2: Likert Questions Interface Trials

Keyword	Survey Questions
Clearness	Q1: I saw a clear relation between the motion and the lights/sounds C1: The lights/sounds did not seem to be correlated with the movements
Comfort	Q2: The light/sound interface made the drive more comfortable C2: My comfort of the drive was decreased by the light/sound interface
Motion vs. Cue	Q3: I was more aware of the light/sound interface than of the motion C3: The motion was more prominent than the light/sound interface
Correctness	Q4: I trusted the information from the interface to be correct C4: I was uncertain if the interface was giving consistent and/or correct information
Intuitiveness	Q5: I quickly knew how to interpret the light/sound information C5: It took me a long time to understand how to interpret the information from the light/sound interface
Intrusiveness	Q6: The light/sound interface felt very intrusive C6: The light/sound interface did not annoy me
Correct Timing	Q7: The timing of the lights/sounds was perfect C7: The timing of light/sound information should be earlier or later

Table J-3: Likert Questions Final Comparison

Keyword	Survey Questions
Clearness	Q1: I prefer a ride without an interface C1: I would prefer a ride with such an interface
Comfort	Q2: The ride itself felt more comfortable with an interface C2: The interface had a negative effect on the ride comfort
Combined vs. Light	Q3: I prefer the light interface over the combined light/sound interface C3: I prefer the combined light/sound interface over the (only) light interface

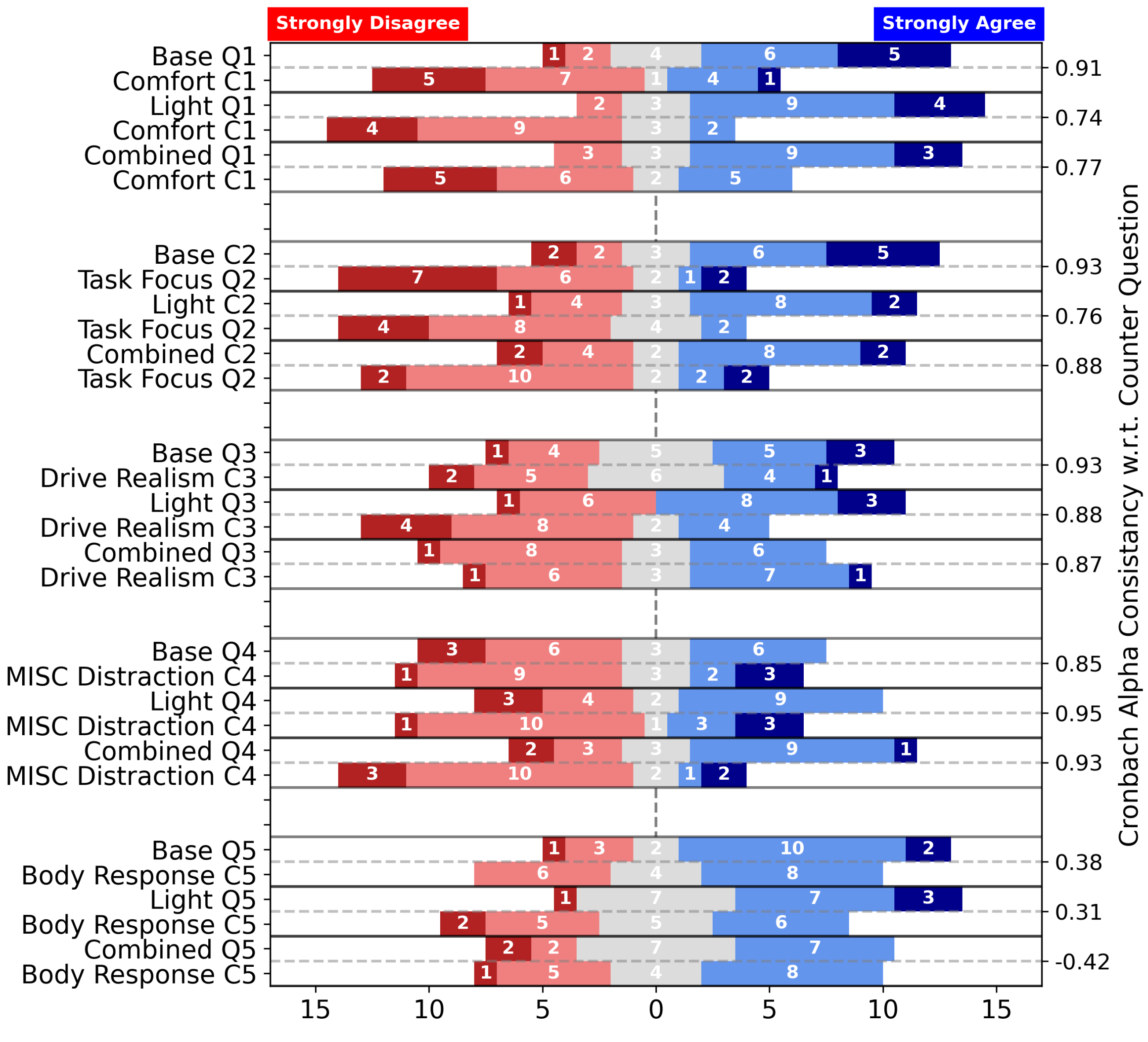


Figure J-1: Likert Answers to Motion Post-Survey Questions

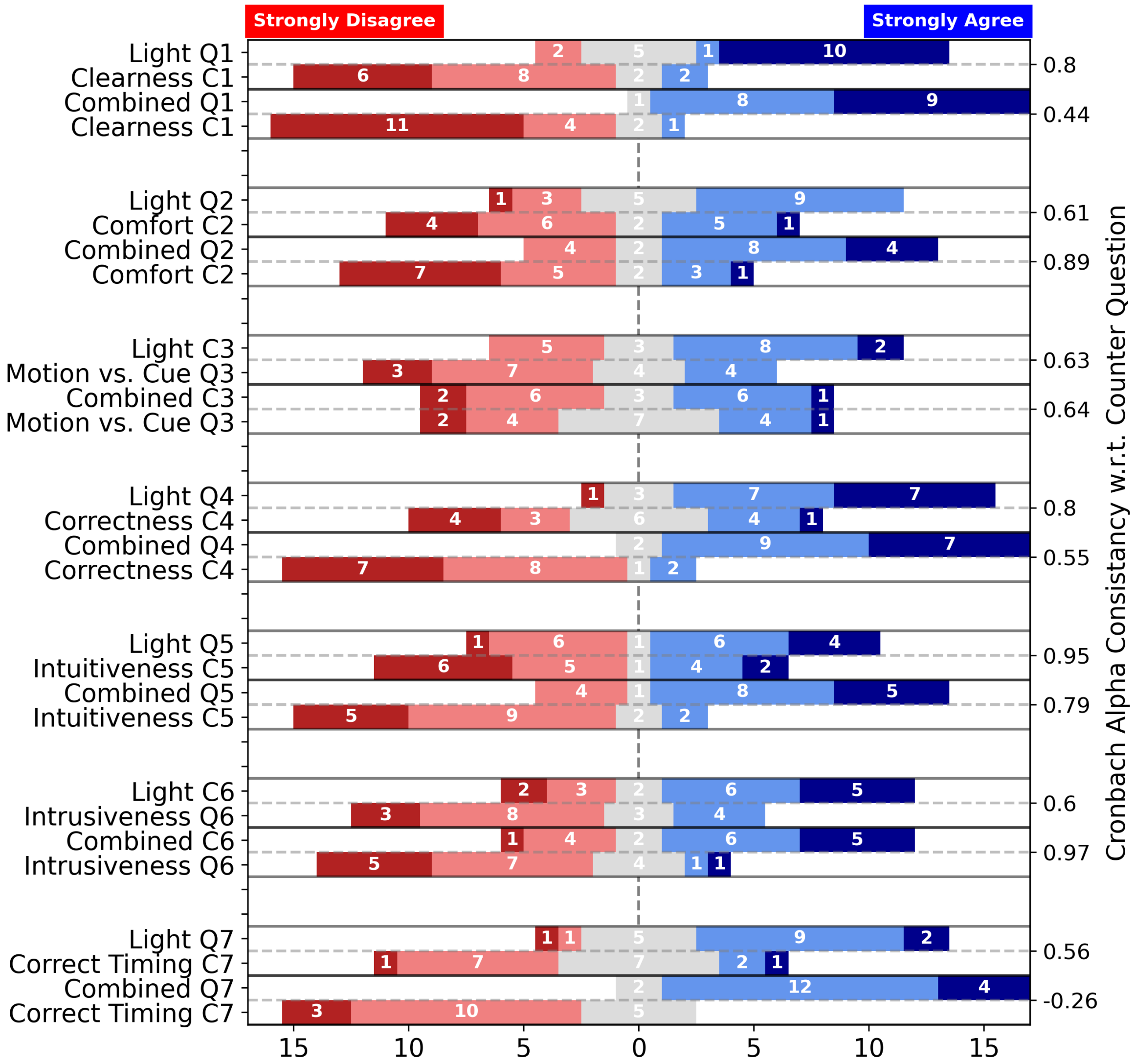


Figure J-2: Likert Answers to Interface Post-Survey Questions

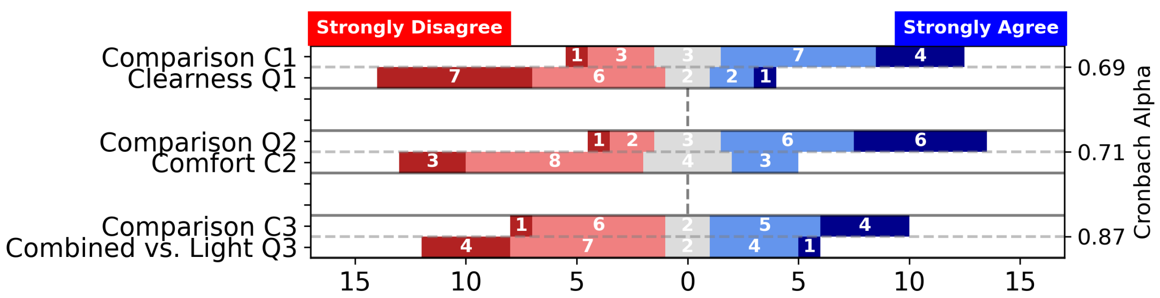


Figure J-3: Likert Answers to Comparison Post-Survey Questions