# Vibrotactile feedforward displays to reduce motion sickness for rear-facing passengers; a VR study

Philip van Veelen

Industrial Design, Eindhoven University of Technology, p.w.j.v.veelenstudent.tue.nl

## Abstract
Traveling while in a reversed seating position increases motion sickness (ms) significantly. When automated vehicles (AVs) will be market-ready, tackling such motion sickness will allow passengers to face each other and enjoy a more home or office-like environment during travel. This affordance would make AVs more desirable and would increase productivity, allowing for more free time. This paper sets out to evaluate vibrotactile feedforward as a solution to this motion sickness in AVs. We will do this by reviewing related works, developing a prototype, and performing a study in a virtual reality environment.

Keywords: Automotive research, Autonomous, Haptic, feedback, Predictive directional feedforward, Virtual Reality

## Introduction
Imagine a future in which travel in a fully automated car is the standard. When there is no need for a steering wheel and pedals, no need to keep eyes on the road, and a comfortable mode to transport in one's bubble, cars can be fully devoted to accommodating non-driving related tasks (NDRTs) [9][13]. Instead of driving, there will be the possibility to work, chat, talk to colleagues, or spend quality time with friends and family. On average, each day Americans spend one hour behind the steering wheel [24]. If leisure or commute is possible during this time, this could improve quality of life significantly, and increase desirability for AVs, making traffic safer. Although safety, economic and societal benefits, efficiency, convenience, and mobility for the disabled [25] are attributed as the reasons why autonomous driving benefits the occupants of a vehicle, the ability to engage in more social situations is an often overlooked opportunity

### Face-to-face interior layouts
To fully benefit from driving in an AV, research indicates that it would be optimal to have an alternative seat layout, compared to the regular rows pointing in the same direction. In a comparative study performed in China and Sweden, participants preferred a face-to-face layout in scenarios when taking long drives, despite the difference in roads, culture, and environment [15]. This futuristic seat configuration is an old idea, since the early automobiles that were developed when horse carriages were the main transportation method, featured a similar layout [7]. Several automotive manufacturers have developed concept cars with face-to-face layouts, such as the Renault Symbioz, Mini Urbanaut, Volkswagen Sedric, and the Volvo 360 concept [26–29]. Avs are predicted to bloom in the sector of Mobility as a Service (MaaS)[13].

### Motion sickness
Carsickness currently already affects approximately one in three passengers[18]. Once cars become self-driving, there is another problem surrounding face-to-face style car interiors, which is the increase of motion sickness experienced when traveling backward [17]. motion sickness is a condition in which movement results in a feeling of unwellness. motion sickness can vary in severity and symptoms on an individual basis, but typically symptoms include nausea, light-headedness, and drowsiness[23]. More severe symptoms are vomiting, loss of conscience, and loss of bowel control.

Motion sickness is caused by a movement that is seldomly experienced or dissonance between perceived vestibular and visual motion. This dissonance is called the Sensory Conflict Theory, and currently is the most accepted explanation of the logic of motion sickness [16]. Dissonance is common when a passenger of a vehicle is not in control of the motions and is not paying attention to the surroundings. By not paying attention, the inability to anticipate movement causes a state of unpreparedness in the occupant of a vehicle. As the movement becomes more unpredictable, the motion sickness increases significantly [11]. By making the occupants unable to see where a vehicle is going, passengers are limited in their ability to see curves and points where the vehicle would accelerate or deaccelerate. That is why rearward driving increases motion sickness significantly [17]. In urban driving scenarios, there are typically more corners and vehicles drive at a less constant speed, causing more vestibular movement[23] [20].

If unpredictable movement increases motion sickness, it is logical that making motions predictable through cues reduces motion sickness. Much successful research has been done regarding feedforward to reduce motion sickness. Methods include visual, auditory, and haptic displays [9,10,22].

## Vibrotactile displays

Vibrotactile displays are actuators that communicate information by causing a sense of vibration through the perception of touch. When used solely, it functions as a non-distracting, discrete and immediate form of communication [21]. Vibrotactile displays can be varied in placement, speed, and intensity. The vibrations can provide occupants with information such as the location of surrounding objects, and the position of the vehicle on the road. According to recent studies [2,3], haptics is a valid modality for vehicles to communicate with their occupants. Although auditory and visual feedback has been proven to be a highly effective method, it can also distract occupants during social or work-related situations, whereas vibrotactile feedback uses a different communication channel. This allows occupants to use their full visual and auditory attention for social interaction. An added benefit is that the method of communication is more inclusive towards people with visual impairments.

Based on this provided information we believe that reducing motion sickness for rear-facing passengers can open up new possibilities for automotive companies, companies, and people who spent much time driving. Driving could be more social, productive, and efficient using face-to-face layouts, but motion sickness will likely be a limiting factor if it is not reduced for rear-facing passengers.

This paper will explore haptic vibrotactile displays aims to solve the aforementioned issue regarding motion sickness, using the research question:

*Can motion sickness for rear-facing AV passengers be reduced through vibrotactile displays in the seat?*

To answer this question we first outline an examination of related works, including several methods of solving motion sickness. Based on the existing research surrounding rearward-facing passenger motion sickness, we then describe our research prototype, which is a device in the car seat that provides rear-facing passengers with predictive directional haptic feedforward to prevent discomfort and disorientation by reducing the dissonance between visual movement and vestibular movement. In the method section, we describe our lab study, in which six participants used the device in a virtual reality (VR) environment. The concept was prototyped and tested by combining digital and physical prototypes. The physical device is a seat that has a vibrotactile display. All resulting data collected is compared and described in the results section. The data is evaluated in the Discussion section.

# Related work

Related works is divided into 5 sections containing the following topics: Evaluation of motion sickness, Haptics and motion sickness, haptic cues, VR testing autonomous vehicles, and the conclusion.

## Evaluation of motion sickness

The Self-Assessment Manikin (SAM) questionnaire is a metric for measuring the comfort levels of a participant. The questionnaires consist of three categories with a bi-axal scale consisting of opposing bodily sensations. The first row gradually changes from happy to sad, the second row changes from excitement to calm, and the third row changes from being controlled to a feeling of being in control.

The Motion Sickness Assessment Questionnaire (MSAQ) is a valid way to measure motion sickness [5]. It consists of 16 symptoms of motion sickness, with a scale of 1 to 9. Participants fill in the scale based on how they feel immediately after a test, and the researcher uses the provided formulas to calculate the severity of motion sickness that occurs. The symptoms are grouped into the gastrointestinal, central, peripheral, and Sopite categories. These categories can be analysed separately, creating more specific data to compare results.

## Haptics and motion sickness

Auditory and visual feedback can distract occupants during social situations, whereas vibrotactile feedback requires different senses. This allows occupants to use their full visual and auditory attention for social interaction. An added benefit is that the method of communication is more inclusive towards people with sensory impairments. Haptic vibrations can be varied in placement, speed, and intensity. The vibrations can provide occupants with information such as the location of surrounding objects, and the position of the vehicle on the road. According to recent studies [2,3], haptics is a valid modality for vehicles to communicate with their occupants. Furthermore, haptics has the benefit of smaller reaction times when compared to auditory ques [30] and visual cues [8].

### Vibrotactile cues

In an AV, the seating provides a guaranteed contact area to send vibrotactile information to the occupant. The placement of haptics in the seating area does not require behavioral change, since seats are necessities in any sort of autonomous vehicle. Therefore there is no requirement to learn the user interaction. When comparing the placement of vibrotactile actuators in the seat pan and the back support, the back-support vibrations are perceived as more urgent [30]

Vibrotactile feedback can be created using Eccentric Rotating Mass (ERM) vibration motors, Linear Resonant Actuators (LRM), or piezo elements. ERM was chosen after testing several motors by feeling the frequency and relative strength. The threshold for vibration frequencies lies around 60 Herz [14]. Haptic cue duration of approximately 2 seconds is most suitable for haptic feedforward [12].

### VR testing autonomous vehicles

Virtual Reality motion sickness symptoms are similar to regular motion sickness, and can also be explained via the Sensory Conflict theory. The difference, between car sickness and virtual reality sickness, is that in virtual reality sickness visual motion is perceived, but the vestibular motion is either lacking or is distorted whenever the virtual position of the first-person view moves. This is why in VR game design it is commonplace to use a sort of teleportation mechanic to avoid this problem [4].

### conclusion

Motion sickness is a subjective phenomenon that can be qualified using self-assessment questionnaires. Haptics

## Method

For this design research, we conducted a lab experiment in which quantitative data was gathered by employing self-assessment questionnaires. The study consisted of a Virtual Reality (VR) experience, combined with a physical proof-of-concept prototype to simulate the context of driving in an autonomous vehicle in a rear-facing position. Although it is likely possible to simulate the autonomous vehicle by using a simulator screen, driving a real car with rear-facing seats, and manually actuating the prototype, or acting out the situation, virtual reality has the advantages of causing real controllable motion sickness, having perfect repeatability and most importantly, whenever the motion sickness becomes excessive, the headset can easily be removed. Furthermore, it is inexpensive compared to simulators and real cars, making the experiment accessible for replication and iteration. Although devices that tilt, rotate, and vibrate to increase realism are available, they are not used in this study due to budgetary limitations. However, as the goal is to determine if there is a causal connection between factors vibrotactile feedforward and a decrease in motion sickness, the test setup should be sufficient to immerse participants in an autonomous vehicle and to cause symptoms of motion sickness.

The participants were selected through the method for convenience sampling from the researcher's social network. For this study, 6 students participated in the range of 18 and 25 years of age. The members are students from the TU/e and are from varying faculties. The age group is chosen since it is anticipated that in 2045 the first level 5 AVs will be sold. Therefore, young adults are the most relevant target group, since they are experienced enough with driving to envision themselves using the vehicle for regular use, and they are experienced enough with modern technology. The students were approached through online social media channels such as WhatsApp and on location at the TU/e.

The study consists of two 5 minute sessions. First, a control group without vibrational feedback was tested, after which the experimental group was tested. After each test, a questionnaire was filled in. The questionnaire data were analyzed in excel to evaluate if the prototype prevents motion sickness. The motion sickness data was cross-referenced with the self-assessment mannequin data to verify the findings and to provide the results with more context and elaboration. The implications of the results are elaborated in the Discussion.

Data collection was done via self-assessment. Since motion sickness is different for each person, it is difficult to quantify severity directly. Although tests have been conducted with measuring sweat, pupil dilation, and body temperature, these metrics are direct physical responses. What is more important for this research, is to know to what extent participants feel the motion sickness. By letting participants rate their sensations, motion sickness can be most accurately diagnosed [1].

The Motion sickness history questionnaire (MSHQ) contains questions regarding past experiences with motion sickness in cars, busses, coaches, small boats, ships, airplanes, and trains. Participants will be asked about the occurrences of the symptoms of motion sickness[6]. This questionnaire can be used to filter out participants with extreme cases of motion sickness, since, as mentioned before, motion sickness can result in very negative experiences.

# Prototype

The user study setup (Figure 1: user study setup) consists of a physical working mechanism and a digital VR environment.


Figure 1: user study setup

The virtual reality environment (Figure 2: Screenshot of the VR environment) is developed for a smartphone, created in the Unity 3d engine, packaged into an Android OS .apk file. The smartphone is fitted into a regular VR headset that is widely available. When the app is activated, the program simulated an autonomous driving experience from the first-person perspective. Using Unity's plug-in framework called XR SDK, the participant will be able to experience VR in a real-time 3D environment [19]. To make the VR experience run smoothly without framerate drops, it was decided to run it natively on the android google cardboard, since streaming via a pc requires a heavy GPU, and either USB or Wi-Fi tethering, causing many hiccups in the system during experimentation. The downside of running the application on a smartphone was a reduction in graphical fidelity, but during experimentation, it was determined that smooth head tracking is vital to gain immersion.

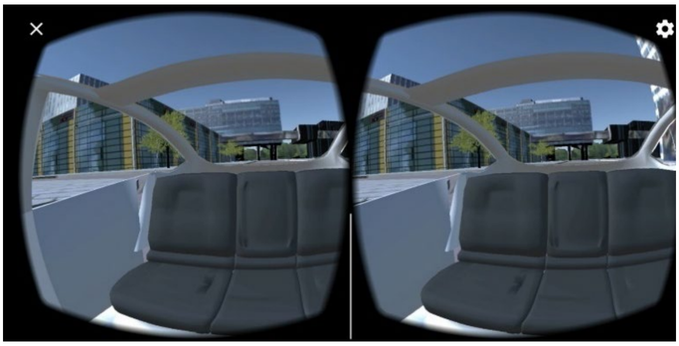

Figure 2: Screenshot of the VR environment

The physical prototype (Figure 3: physical prototype) consists of a seat that has been equipped with four vibrational motors. Two motors are placed on the seat within the cushioning beneath the posterior contact area of the passenger. These small vibrating DC motors are connected to an Arduino Uno microcontroller. The Arduino controller is used to control the direction and duration of the vibrational feedback. The seat is made from EVA foam material to ensure comfortable seating. The attachment of the vibrational motors to the seat is done using silicone since after experimentation, it was concluded that fixing them into place without flexibility reduced vibrations.

The corner times of the VR app were logged in the unity console using the debug feature to make the Arduino send feedforward at precisely the right timestamps.

Since the motor has a sufficient frequency above the human threshold, no programming was required to tweak the device. After experimentation, it was decided that the controller vibrates the motor two seconds before each turn and shuts the motors off when the car is starting to make the turn. The Arduino was programmed with the simple delay function to run synchronously along with the VR app.

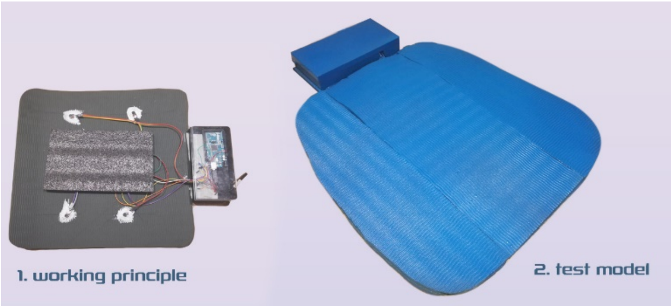


Figure 3: physical prototype

# Findings

the results of the Self-Assessment Manikin questionnaire are displayed in figure 4: SAM results. Note that in the graphs each category has only one label, however, in the questionnaire, there is an opposite label across, so excitement decreased, while calms increased. Positive emotion increased while negative emotion decreased, and the sense of control increased while the sense of being controlled decreased. Whereas positive emotion and sense of control are certainly positive improvements, excitement and calm are more context-related, however, in a self-driving car calm is likely to be more desirable.

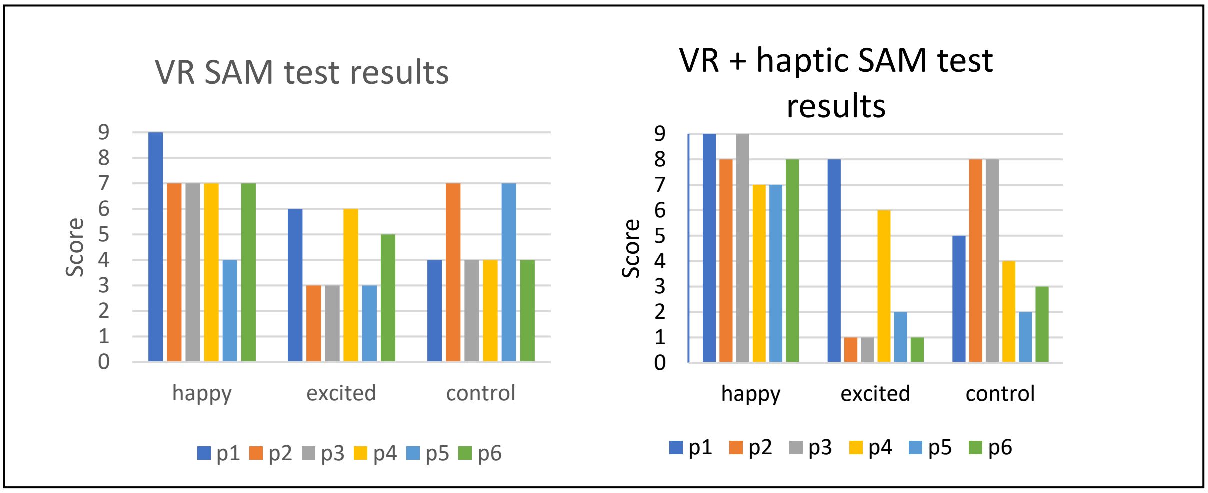


Figure 4: SAM results

In the motion sickness assessment questionnaire results displayed in figure 5: MSAQ results, it is notable that all categories of motion sickness symptoms have decreased on average, and that when the haptic feedback is introduced, most participants' symptoms were reduced to the lowest category of severeness.

The motion sickness score is calculated by adding the scores per person, dividing them by 144, and then multiplying them by 100. The average motion sickness score of the control group is 20.72. The group with the haptic feedback had an average score of 14.12. This means that in the second test the motion sickness has been decreased by 6.6 points or 31,85%.

In the gastrointestinal-related category (appendix (Xd) every symptom has been reduced to the lowest possible value. The symptom 'I feel as if I may vomit' was already at the lowest value, so this was not possible to decrease even more. The score decreased from  16,2 to 11.1.

In the central category (appendix (Xe)), all symptoms have been decreased, but there is still room for further reduction. It is notable that P4, the participant with a higher score for motion sickness susceptibility, felt significant lightheadedness even when the haptic feedforward was provided. This can be considered an outlier, however, all other symptoms were still reduced. The score decreased from 23.7 to 10.7

In the peripheral category (appendix (Xf)) the scores were relatively low in the control group, but the average score still decreased after the intervention. The score decreased from 16.0 to 11.7.

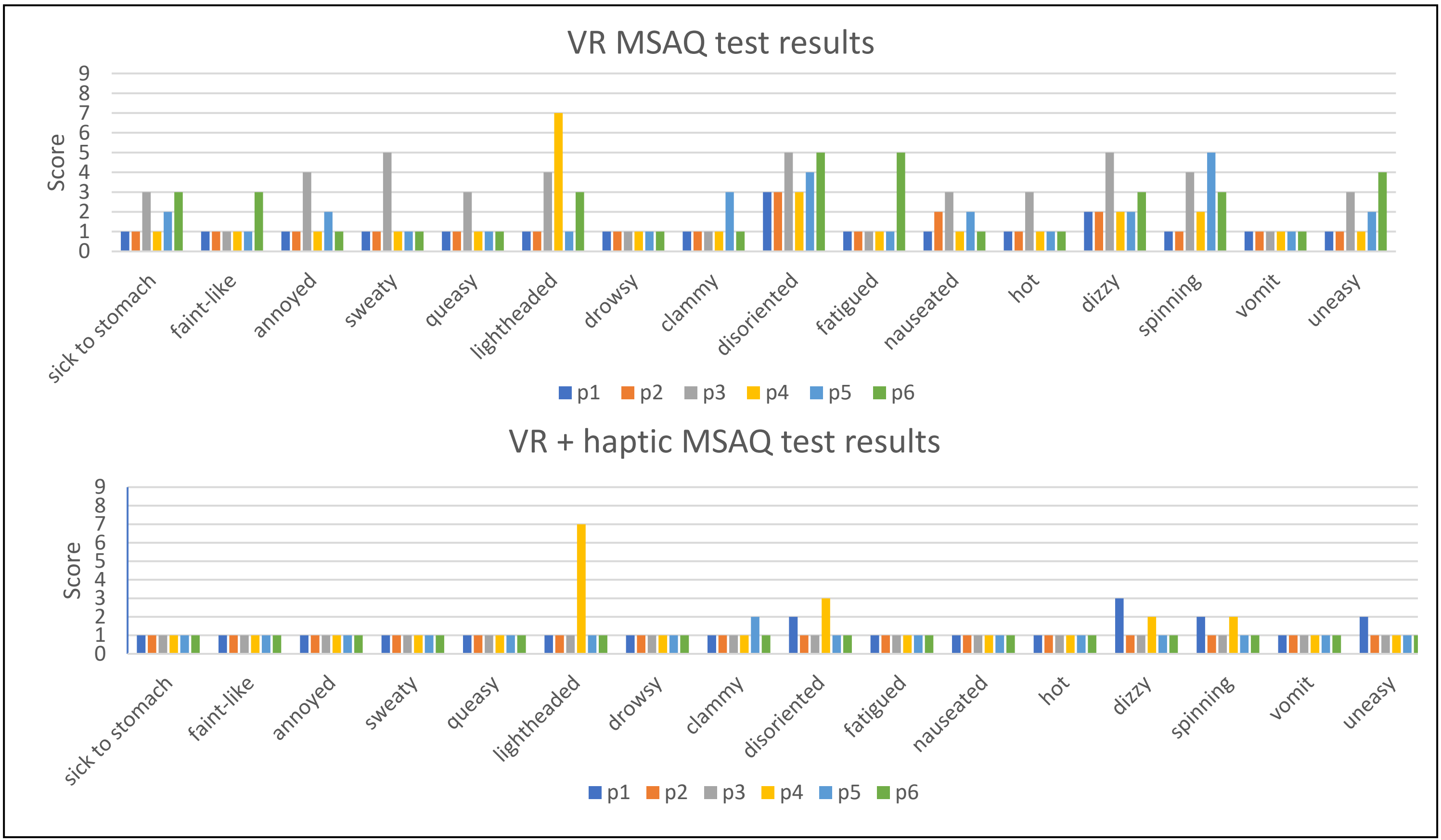


Figure 5: MSAQ results

In the Sopite-related category (appendix (Xg) the measurements have been reduced, except for drowsy, which was already at the lowest possible value. What is notable though, is that P1 became slightly more uneasy with the addition of haptic vibrations. This is the only instance of a participant's score of a symptom increasing during the intervention part of the study.

# Discussion

## Results

The motion sickness score has been significantly reduced when comparing the control group with the experimental group by implementing vibrotactile feedforward in the simulated driving route. Therefore the hypothesis was proven correct in this study, meaning that in this scenario vibrotactile haptic feedforward reduces motion sickness for rear-facing passengers.

What has been shown, however, is that using the vibrotactile feedback reduces the dissonance between visual and vestibular cues. This means that vibrotactile feedforward is a potent method of providing rear-facing passengers with directional cues to decrease the unpredictability of movements.

Besides the reduction of the motion sickness, the experimental group resulted in a change in SAM values as well. Happiness increased overall, but exited/ relaxed and in control/ being controlled seemed to be further divided.

Although happiness is likely directly linked to reduced motion sickness, the other values are difficult to determine if they are linked to the prototype, or improved MS score.

It should be taken into account that this study was conducted in a controlled environment without the vestibular movement of an AV.

### Limitations

This results in differentiation from reality, by inducing a different type of motion sickness. In the test, the participants saw movement but did not feel it, whereas, in a real driving scenario, the occupant feels movement, but does not get sufficient visual stimulation to predict this movement. This means that to see the full effect, a study with real rear-facing urban driving is required. Due to budgetary constraints and the required safety for participants, this was out of scope for this study.

In automotive research conducted by students, compromises are commonplace since purchasing, modifying, and testing real vehicles can result in unethical practice, requires a high budget, and has more variables when replicating tests, due to the varying road, weather, and traffic conditions.

A point of improvement is the relatively small group of participants. Due to the inexperience of the researcher, the population was relatively low compared to similar studies. Even so, valuable data and a clear correlation were shown.

Even though several hours were spent between the control and experimental group, it is still possible that the participants became familiarized with the VR environment. This might have created a positive bias towards the haptic device.

### Future work

Despite the strong correlation, it is safe to conclude that further research needs to be conducted to prove this correlation in a bigger population with a setup that includes (simulated) physical movement as mentioned before, but other inclusions could be the addition of (simulated) social interaction, VR-based NDRT's, watching a video while driving, or doing cognitive tests to check how motion sickness is influenced in a more elaborate simulated user context. Especially the social interaction in a simulated VR vehicle is relevant in 2021/2022 with the emerging threat of covid making it difficult to evaluate multiple-user scenarios safely. The emerging mobility as a service trend could benefit from user experience studies since when the technology is finally ready, it will be vital to ensure smooth interaction with AVs. Forms of this type of research have already been done by the BMW group [27], but for universities, this can greatly reduce the risks of planning user tests, and being unable to conduct those tests due to changing laws.

Outside of automotive research, and accessible method for students was used to evaluate scenarios that are non-existent or costly to simulate adequately. Using the combination of physical prototyping and virtual environments more extreme can be evaluated and refined long before the technologies might be physically possible to achieve.

## Conclusion

In this paper, a study was done to test if haptic vibrational feedforward can reduce motion sickness for rear-facing passengers of autonomous vehicles, by evaluating a physical prototype within a VR simulated user context. The results of the questionnaires indicate a strong correlation. This is supported by the following conclusions from the literary research:
1. predictable movement causes less motion sickness than unpredictable movement
2. Haptic feedback is a successfully proven method of conveying spatial and directional information to passengers of a vehicle.

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# Appendix A: Subject information for participation in scientific research

Evaluating predictive haptic feedforward seats in a rear-facing automated vehicle

Introduction

Dear Sir/Madam,

You are asked to take part in a scientific study.

Participation is voluntary. Participation requires your written consent. Before you decide whether you want to participate in this study, you will be explained what the study involves. Please read this information carefully and ask the investigator for an explanation if you have any questions. You may also discuss it with your partner, friends, or family.

## General information

For this study, 6 participants from different countries are required. All participants are expected to participate at the TU/e.

## Purpose of the study

The goal of this study is to explore haptic feedforward in relation to motion sickness during rear-facing urban automated driving scenarios in a VR simulated context.

**1. What participation involves**

You will be asked to participate in two sessions of a VR simulation of a self-driving car in a rear-facing seat and will see a simple cognitive test while being immersed in the automated vehicle. The two sessions take place on two different days. Before the first session, you will be asked to fill in the Motion Sickness History Questionnaire to see how susceptible you are to motion sickness and to determine if it is okay for you to participate in the study. After both study sessions, you will be asked to fill in two surveys.

The two individual sessions will take 10 minutes each, and the questionnaires should be completed within 10 minutes as well.

**5. Risks**

As stated before, The goal of this study is to explore haptic feedforward in relation to motion sickness. Although VR is a safe technology, you may be extra sensitive to virtual motion sickness. To avoid participants becoming unwell, you will be asked to fill in the Motion Sickness History Questionnaire before the study. If you score insufficiently on this test, you will be excluded from this study for your well-being.

**2. What is expected of you**

To carry out the study properly is important that you follow the study instructions.

- If you have questions about the study, ask the researcher.
- Whenever you feel nauseated, uncomfortable, or do not want to continue the test, please take off your headset and inform the researcher immediately. The study will be stopped.
- If you would like to know more about the use of the data, or study beforehand or after the study, feel free to reach out. P.w.j.v.veelen@student.tue.nl
- You will partake in two sessions, each session being on a different day.
- If your contact information changes, contact the researcher via the aforementioned email address or +316-48-093-23
- You fill in the questionnaires truthfully

**You must contact the investigator:**

- if you no longer want to participate in the study.
- if your contact details change.
- If you want to change or cancel the date and time of the study

### 6. If you do not want to participate or you want to stop participating in the study

It is up to you to decide whether or not to participate in the study. Participation is voluntary.

If you do participate in the study, you can always change your mind and decide to stop, at any time during the study. You do not have to say why you are stopping, but you do need to tell the investigator immediately.

The data collected until that time will still be used for the study.

If there is any new information about the study that is important for you, the researcher will let you know. You will then be asked whether you still want to continue your participation.

### 7. End of the study

Your participation in the study stops when

- you choose to stop
- the end of the second study has been reached
- the investigator considers it best for you to stop

The study is concluded once all the participants have completed the study.

### 8. Usage and storage of your data

No personal data will be collected, used, or stored for this study.

### 9. Any questions?

If you have any questions, please contact the researcher.

If you have any complaints about the study, you can discuss this with the researcher. All the relevant details can be found in Appendix A: Contact details.

### 10. Signing the consent form

When you have had enough time to think about the study, the involved tasks, and the processing of your data, you will be asked if you want to participate in this study. If you give your written consent, you indicate that you have understood the information and consent to participate in the study. The signature sheet is kept by the investigator. Both the Investigator and yourself receive a signed version of this consent form.

Thank you for your attention.

# Appendix B: Contact details for researcher, Project coach, and  Ethical Board Review

**Researcher:**

Philip van Veelen

p.w.j.v.veelenstudent.tue.nl

+31 6 24809323

**Complaints:**

Project coach:

Bart Hengeveld

b.j.hengeveld@tue.nl

**For more information about your rights:**

https://www.tue.nl/en/our-university/library/rdm/rdm-themes/privacy-and-ethics/

# Appendix C: Subject Consent Form

Evaluating predictive haptic feedforward seats in a rear-facing automated vehicle

- I have read the subject information form. I was also able to ask questions. My questions have been answered to my satisfaction. I had enough time to decide whether to participate.
- I know that participation is voluntary. I know that I may decide at any time not to participate after all or to withdraw from the study. I do not need to give a reason for this.
- I give permission for the collection and use of my data to answer the research question in this study.
- I know that some people may have access to all my data to verify the study. These people are listed in this information sheet. I consent to the inspection by them.

- I □ do
  □ do not
  consent to keeping my personal data longer and to use it for future research.
- I □ do
  □ do not
  consent to being contacted again after this study for a follow-up study.
- I want to participate in this study.

**Name of study subject:**

Signature: Date: __ / __ / __

------------------------------------------------------------------------------------------------------------------

I hereby declare that I have fully informed this study subject about this study.

If information comes to light during the study that could affect the study subject's consent, I will inform him/her of this in a timely fashion.

Name of investigator: Philip van Veelen

Signature: Date:__ / __ / __

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# Appendix D: the Motion Sickness History Questionnaire

NAME.......................................... AGE..........................

COURSE......................................... YEAR.........................

TELEPHONE NUMBER.......................... EMAIL.......................

APPROXIMATE BODY WEIGHT................ HEIGHT......................

1. In the past YEAR, how many times have you travelled AS A PASSENGER in the following types of transport?

| | NEVER | 1 | 2-3 | 4-15 | 16-63 | 64-255 | 256+ |
|---|---|---|---|---|---|---|---|
| CARS | | | | | | | |
| BUSES | | | | | | | |
| COACHES | | | | | | | |
| SMALL BOATS | | | | | | | |
| SHIPS | | | | | | | |
| AEROPLANES | | | | | | | |
| TRAINS | | | | | | | |

2. In the past YEAR, how many times have you felt ill, whilst travelling AS A PASSENGER in the following types of transport?

| | NEVER | 1 | 2 | 3 | 4-7 | 8-15 | 16+ |
|---|---|---|---|---|---|---|---|
| CARS | | | | | | | |
| BUSES | | | | | | | |
| COACHES | | | | | | | |
| SMALL BOATS | | | | | | | |
| SHIPS | | | | | | | |
| AEROPLANES | | | | | | | |
| TRAINS | | | | | | | |

3. In the past YEAR, how many times have you VOMITED whilst travelling AS A PASSENGER in the following types of transport?

| | NEVER | 1 | 2 | 3 | 4-7 | 8-15 | 16+ |
|---|---|---|---|---|---|---|---|
| CARS | | | | | | | |
| BUSES | | | | | | | |
| COACHES | | | | | | | |
| SMALL BOATS | | | | | | | |
| SHIPS | | | | | | | |
| AEROPLANES | | | | | | | |
| TRAINS | | | | | | | |

4. Do you EVER feel HOT or SWEAT whilst travelling AS A PASSENGER in the following types of transport?

| | NEVER | OCCASIONALLY | OFTEN | ALWAYS |
|---|---|---|---|---|
| CARS | | | | |
| BUSES | | | | |
| COACHES | | | | |
| SMALL BOATS | | | | |
| SHIPS | | | | |
| AEROPLANES | | | | |
| TRAINS | | | | |

5. Do you EVER suffer from HEADACHES whilst travelling AS A PASSENGER in the following types of transport?

| | NEVER | OCCASIONALLY | OFTEN | ALWAYS |
|---|---|---|---|---|
| CARS | | | | |
| BUSES | | | | |
| COACHES | | | | |
| SMALL BOATS | | | | |
| SHIPS | | | | |
| AEROPLANES | | | | |
| TRAINS | | | | |

6. Do you EVER suffer from LOSS/ CHANGE OF SKIN COLOUR (go pale) whilst travelling AS A PASSENGER in the following types of transport?

| | NEVER | OCCASIONALLY | OFTEN | ALWAYS |
|---|---|---|---|---|
| CARS | | | | |
| BUSES | | | | |
| COACHES | | | | |
| SMALL BOATS | | | | |
| SHIPS | | | | |
| AEROPLANES | | | | |
| TRAINS | | | | |

7. Do you EVER suffer from MOUTH WATERING whilst travelling AS A PASSENGER in the following types of transport?

| | NEVER | OCCASIONALLY | OFTEN | ALWAYS |
|---|---|---|---|---|
| CARS | | | | |
| BUSES | | | | |
| COACHES | | | | |
| SMALL BOATS | | | | |
| SHIPS | | | | |
| AEROPLANES | | | | |
| TRAINS | | | | |

8. Do you EVER feel DROWSY whilst travelling AS A PASSENGER in the following types of transport?

| | NEVER | OCCASIONALLY | OFTEN | ALWAYS |
|---|---|---|---|---|
| CARS | | | | |
| BUSES | | | | |
| COACHES | | | | |
| SMALL BOATS | | | | |
| SHIPS | | | | |
| AEROPLANES | | | | |
| TRAINS | | | | |

9. Do you EVER feel DIZZY whilst travelling AS A PASSENGER in the following types of transport?

| | NEVER | OCCASIONALLY | OFTEN | ALWAYS |
|---|---|---|---|---|
| CARS | | | | |
| BUSES | | | | |
| COACHES | | | | |
| SMALL BOATS | | | | |
| SHIPS | | | | |
| AEROPLANES | | | | |
| TRAINS | | | | |

10. Do you EVER suffer from NAUSEA (stomach discomfort, feeling sick) whilst travelling AS A PASSENGER in the following types of transport?

| | NEVER | OCCASIONALLY | OFTEN | ALWAYS |
|---|---|---|---|---|
| CARS | | | | |
| BUSES | | | | |
| COACHES | | | | |
| SMALL BOATS | | | | |
| SHIPS | | | | |
| AEROPLANES | | | | |
| TRAINS | | | | |

11. Have you EVER vomited whilst travelling AS A PASSENGER in the following types of transport?

| | NO | YES |
|---|---|---|
| CARS | | |
| BUSES | | |
| COACHES | | |
| SMALL BOATS | | |
| SHIPS | | |
| AEROPLANES | | |
| TRAINS | | |

12. Would you avoid any of the following types of transport beacuse of motion sickness ?

| | NEVER | OCCASIONALLY | OFTEN | ALWAYS |
|---|---|---|---|---|
| CARS | | | | |
| BUSES | | | | |
| COACHES | | | | |
| SMALL BOATS | | | | |
| SHIPS | | | | |
| AEROPLANES | | | | |
| TRAINS | | | | |

13. Which of the following best describes your SUSCEPTIBILITY to motion sickness?

| | |
|---|---|
| MUCH LESS THAN AVERAGE | |
| LESS THAN AVERAGE | |
| AVERAGE | |
| MORE THAN AVERAGE | |
| MUCH MORE THAN AVERAGE | |

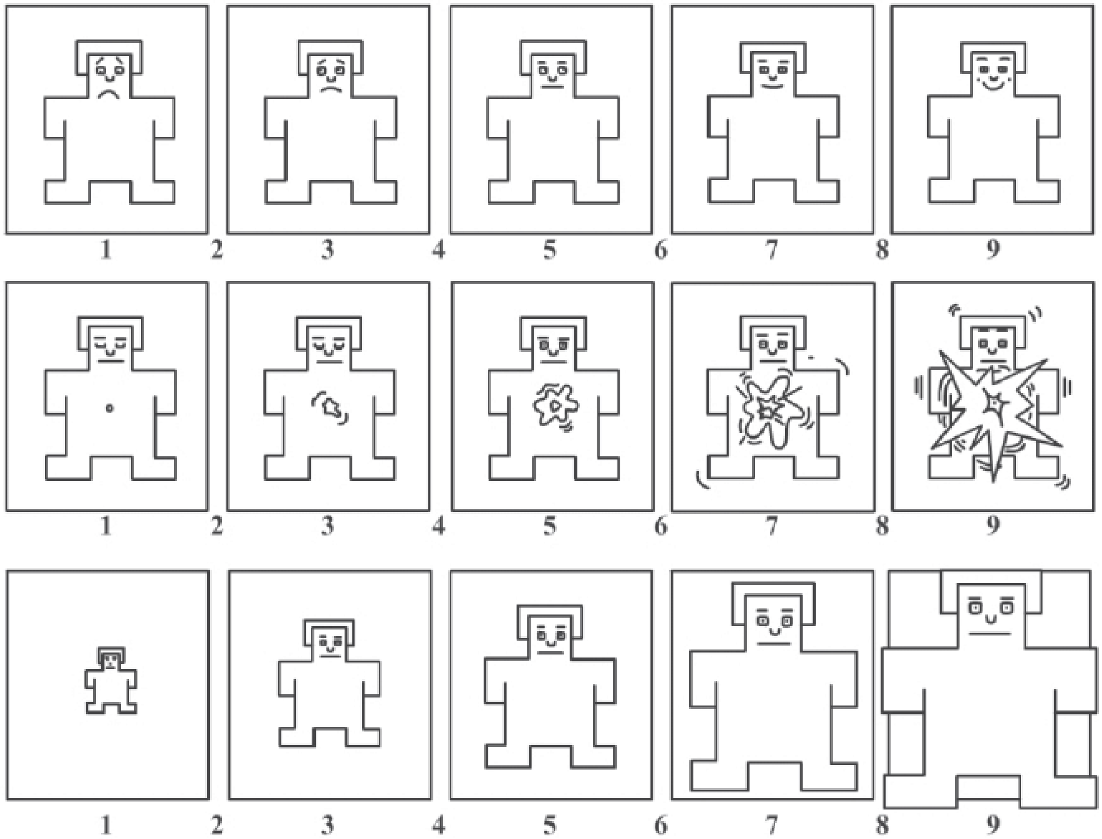
14. Have you ever suffered from any serious illness or injury ?

☐ NO ☐ YES

15. Are you under medical tretament or suffering a disability affecting daily life. ?

☐ NO ☐ YES

# Appendix E: SAM (Self-Assessment Manikin)




Soares, Ana & Pinheiro, Ana & Costa, Ana & Frade, Sofia & Comesaña, Montserrat & Pureza, Rita. Self-Assessment Manikin (SAM) for valence, arousal, and dominance. (2013). Affective auditory stimuli: Adaptation of the International Affective Digitized Sounds (IADS-2) for European Portuguese. Behavior research methods. 45. 10.3758/s13428-012-0310-1.

# Appendix F: MSAQ (Motion Sickness Assessment Questionnaire)

MOTION SICKNESS ASSESSMENT QUESTIONNAIRE (MSAQ).

***Instructions.* Using the scale below, please rate how accurately the following statements describe your experience**

Not at all ... Severely

1——2——3——4——5——6——7——8——9

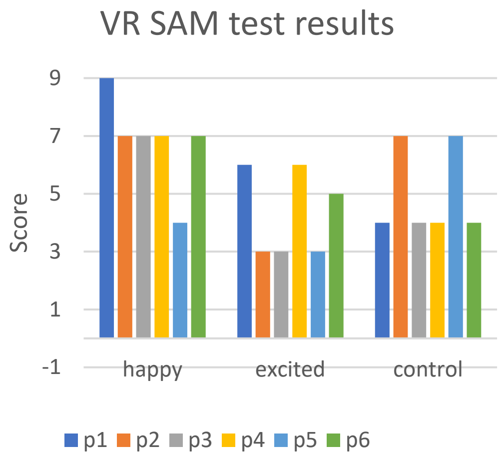
| | |
|---|---|
| 1. I felt sick to my stomach (G) | 9. I felt disoriented (Q |
| 2. I felt faint-like (C) | 10. I felt tired/fatigued (S) |
| 3. I felt annoyed/irritated (S) | 11. I felt nauseated (G) |
| 4. I felt sweaty (P) | 12. I felt hot/warm (P) |
| 5. I felt queasy (G) | 13. I felt dizzy (C) |
| 6. I felt lightheaded (C) | 14. I felt like I was spinning (C) |
| 7. I felt drowsy (S) | 15. I felt as if I may vomit (G) |
| 8. I felt clammy/cold sweat (P) | 16. I felt uneasy (S) |

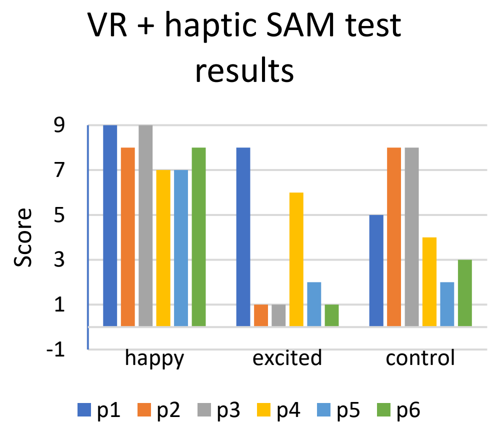
*Note*. G; Gastrointestinal; C: Central; P: Peripheral; SR; Sopite-related.

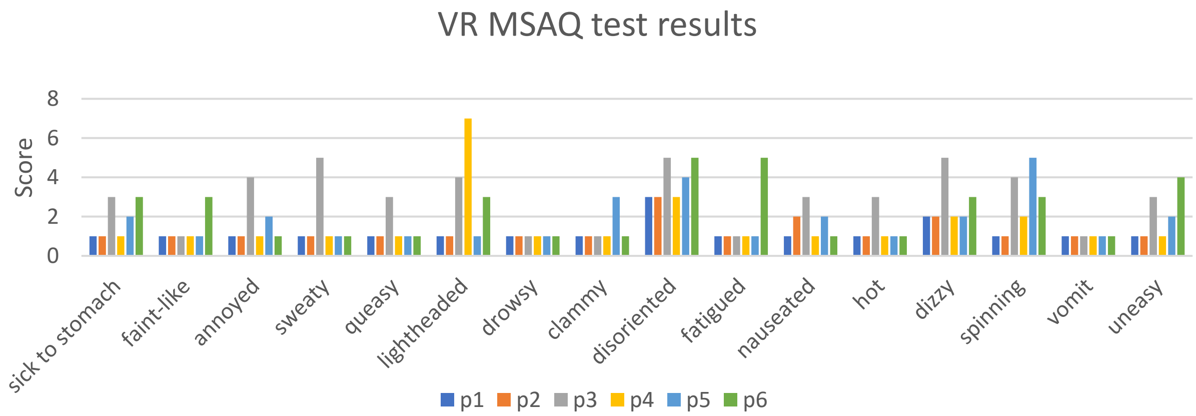
The overall motion sickness score is obtained by calculating the percentage of total points scored: (sum of points from all items/144) × 100. Subscale scores are obtained by calculating the percent of points scored within each factor: (sum of gastrointestinal items/36) × 100; (sum of central items/45) × 100; (sum of peripheral items/27) × 100; (sum of sopite-related items/36) × 100.

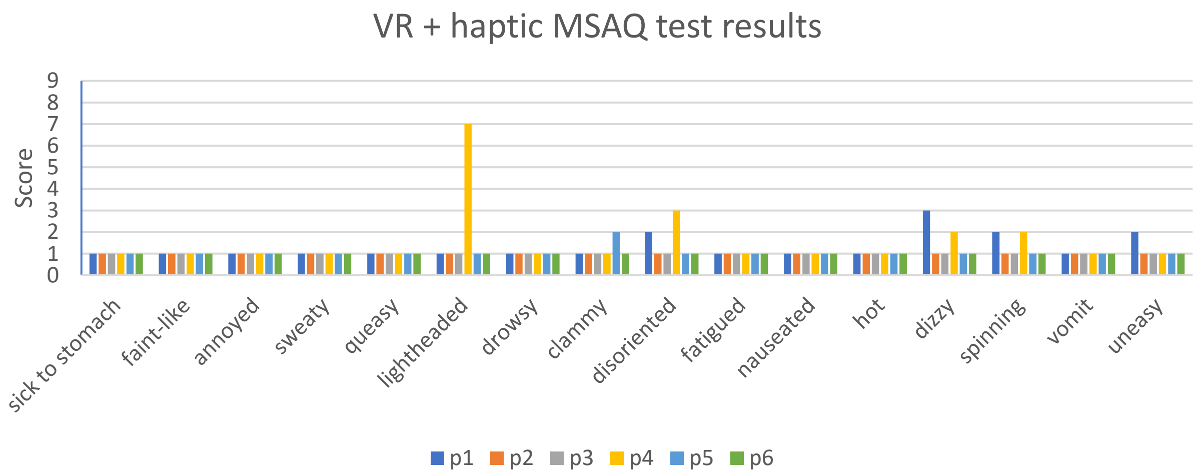
Source: Gianaros, Peter & Muth, Eric & Mordkoff, Jonathan & Levine, Max & Stern, Robert. (2001). A Questionnaire for the Assessment of the Multiple Dimensions of Motion Sickness. Aviation, space, and environmental medicine. 72. 115-9.

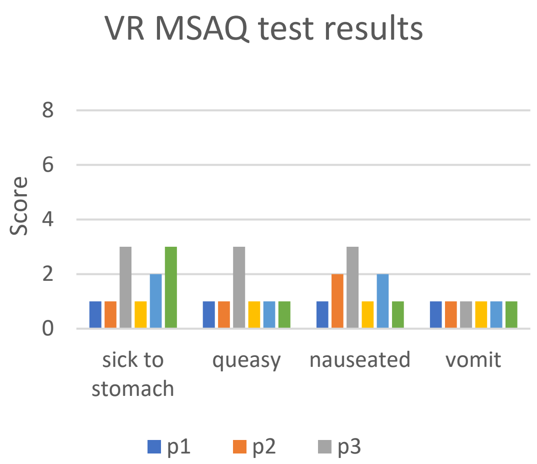
# Appendix G: Questionnaire results

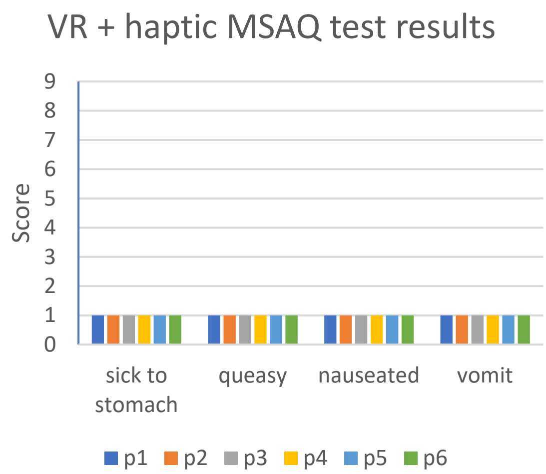


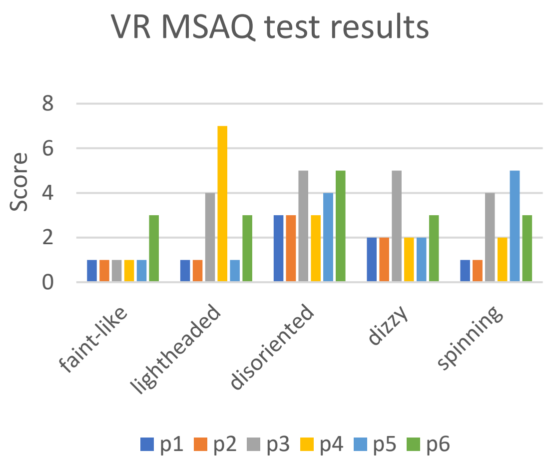



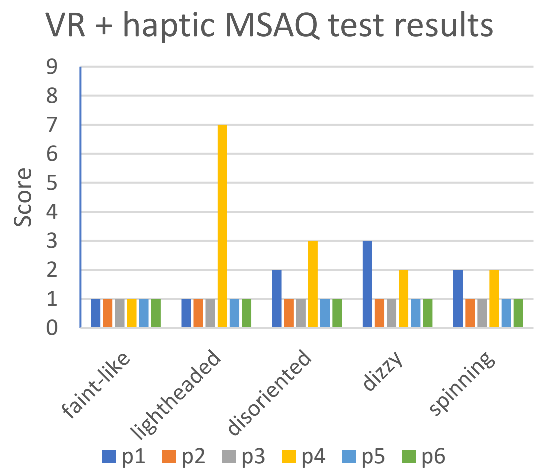



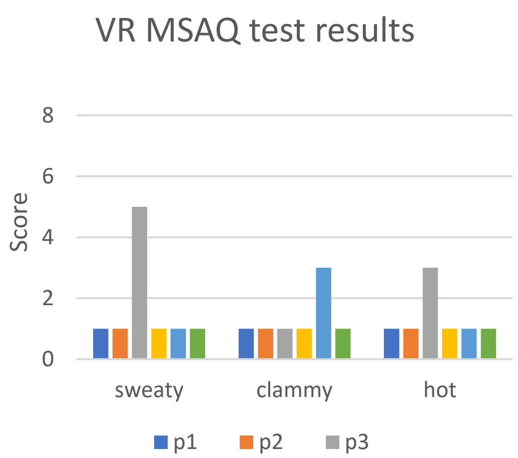



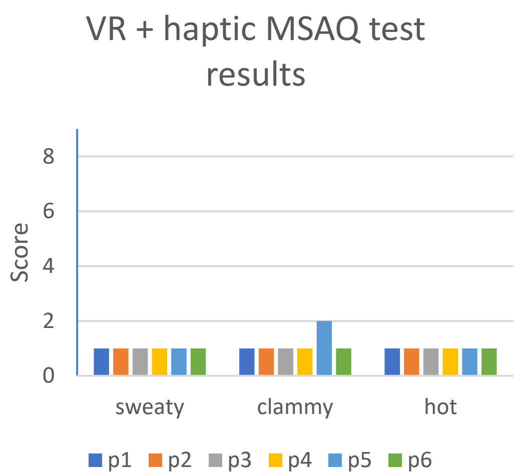

VR MSAQ test results
Score
0
2
4
6
8
sick to stomach
queasy
nauseated
vomit
p1
p2
p3

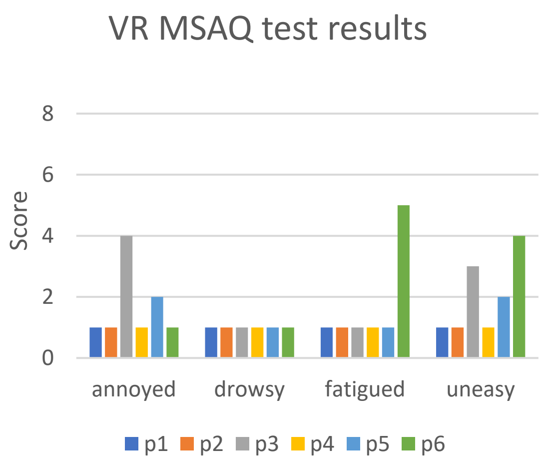

VR + haptic MSAQ test results
Score
0
1
2
3
4
5
6
7
8
9
sick to stomach
queasy
nauseated
vomit
p1
p2
p3
p4
p5
p6


VR MSAQ test results
Score
0
2
4
6
8
faint-like
lightheaded
disoriented
dizzy
spinning
p1
p2
p3
p4
p5
p6

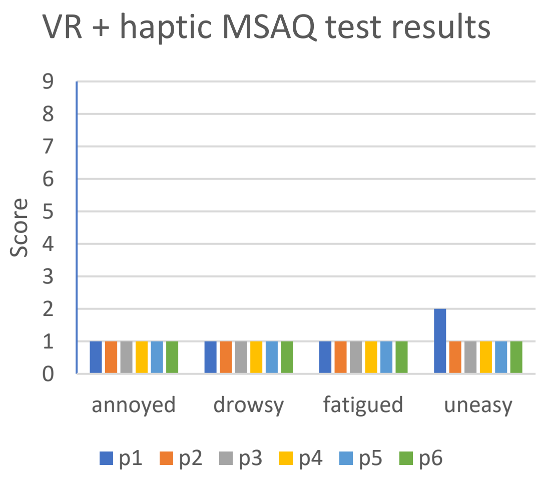

VR + haptic MSAQ test results
Score
0
1
2
3
4
5
6
7
8
9
faint-like
lightheaded
disoriented
dizzy
spinning
p1
p2
p3
p4
p5
p6


VR MSAQ test results
Score
0
2
4
6
8
sweaty
clammy
hot
p1
p2
p3


VR + haptic MSAQ test results
Score
0
2
4
6
8
sweaty
clammy
hot
p1
p2
p3
p4
p5
p6



VR MSAQ test results
Score
8
6
4
2
0
annoyed
drowsy
fatigued
uneasy
p1 p2 p3 p4 p5 p6

VR + haptic MSAQ test results
Score
9
8
7
6
5
4
3
2
1
0
annoyed
drowsy
fatigued
uneasy
p1 p2 p3 p4 p5 p6