THESIS REPORT

EFFECT OF MOTION AND MOTIVATION ON TASK PERFORMANCE, WORKLOAD AND MOTION SICKNESS

Submitted to :
Cognitive Robotics Dept.

Submitted by :
Adarsh Pattanayak (4784553)

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Delft University of Technology

Abstract

Following the literature review, our goal was to study the effect and interaction of motion sickness and motivation on cognitive performance in a reading comprehension task and the associated workload with the task. We chose UCKAT reading tasks for our cognitive task, monetary incentive and ranks as our motivator and a multisine sickening motion profile on a simulator as our motion variable. We exposed participants to 4 conditions, employing a within-subject experiment design, manipulating our independent variables motion and motivation. We collected motion sickness data via the motion sickness susceptibility questionnaire, misery scale and motion sickness assessment questionnaire; motivation data via the situational motivation scale; workload data via the NASA TLX workload scale and task performance data via the total score obtained, the total time spent on the task and the average time spent per question. We found that our motion profile caused motion sickness in participants, with some evidence for habituation. We also found some evidence for training effects present in our data. Performance decrements, associated workload and motivation scores across the 4 conditions were statistically similar and we could not conclusively prove our hypotheses. Further analysis showed that amotivation scores almost showed significant effect on task performance which does match anecdotal evidence. MSAQ scores also negatively affected how much time people could spend on a cognitive task. We found that workload scores of participants increased significantly with increase in motion sickness which could give us an insight on performing cognitive tasks under sickness. Overall, our experiment design could not show the trends that we had hypothesized, and we obtained partial results via our secondary analysis. Our findings indicate that further attention is to be given to the motivation variable to make it more robust. Further, a much large sample size is needed to better test our hypotheses, with perhaps, a mixed subject design for our study. Our study also showed an unexpected interaction of lateral and londitudinal motion profiles, causing significantly higher levels of sickness than what was predicted using existing models, which warrants further research into the same.

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Part I

Literature Review and Introduction of Research Question

Chapter 1

Introduction

Automated cars with drivers out of the loop are closer than ever to becoming a reality. It is anticipated that the active role of the driver may cease to exist and all the people inside will become passengers. Google's driverless cars are clocking up thousands of miles with no mishap and several states in the US, UK and Japan have passed laws allowing supervised automated cars for R&D purposes [Diels, 2014]. Several major automobile companies have launched semi-autonomous vehicles in 2020-2021 including GM (Cadillac CT6, Cadillac Escalade, Chevy Bolt), Mercedes (E-Class, S-Class) and Nissan (Rogue, Leaf). Such semi-autonomous vehicles can, on demand, take over the longitudinal and lateral vehicle control. Many more functions can in principle, be taken over by the vehicle which effectively disconnects the driver from the control loop. The society of automotive engineers define five levels of automation, with my report focused on levels 3, 4 and 5 of automation as shown in the diagram below.

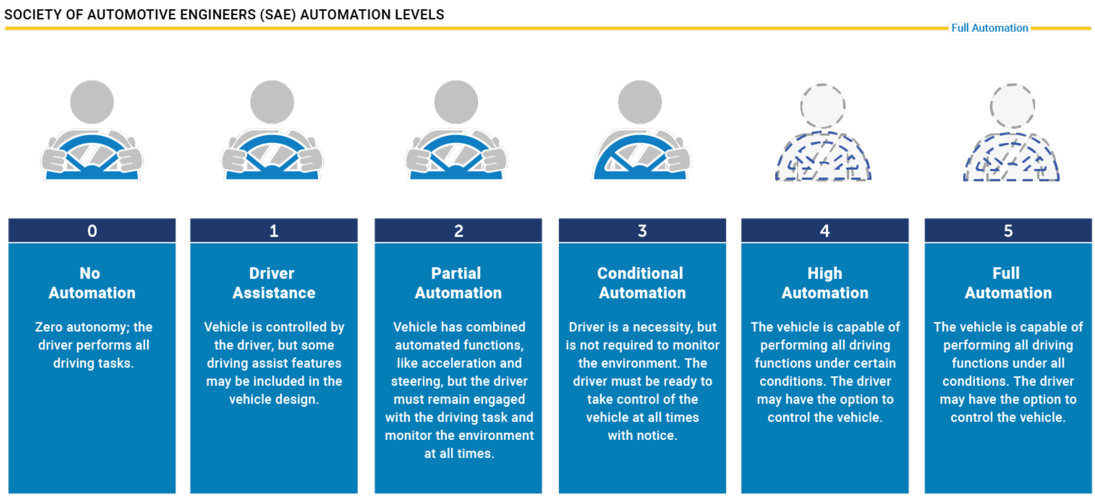

Figure 1.1: Automation levels

With the driver out of the loop, we have the potential to make road transportation more efficient and safer, whilst reducing emissions [Robinson T., 2010]. With the automated system controlling the vehicle, passengers can relax, drink a cup of coffee, check emails or swivel their chairs to face other passengers and converse [Diels, 2014]. Stanley [2015] estimates that 'the productivity gains in automated cars would come to 507 billion dollars in the US' with the introduction of automated cars.

As human factors engineers, we sometimes come across unexpected impacts of automation on the human supervisor. A better understanding of all the possible human-machine interactions must be carefully studied to ensure that these cars are successfully designed and widely accepted. Most of the current research revolves around the topics of transfer of control, interface design, mixed traffic and obstacle conditions and reliability[Diels, 2014]. However, one of the expected effects on the passengers which could potentially reduce productivity and comfort is motion sickness. Another alarming possible effect in level 3 automation cars would be driver performance after he has retaken control of the vehicle from the automation. Vehicles under this category, for example, Audi's 'Traffic Jam Pilot' give a 10 second warning before handing back control to the driver. Melcher et al. [2015], a well cited report which gave various suggestions and recommendations for vehicle handover, based the recommendations assuming normal human performance ability (visual, cognitive and physical) on retake. However, Golding and Stott [1997] found that even when experiencing subjectively low levels of discomfort (along with associated performance decrements), it would not be wise to hand over complete control of the vehicle to a human within the 10 second takeover time period, especially when subjective recovery from motion sickness takes, on average, 15-30 minutes, highlighting a potentially significant mismatch between expected human performance and actual human performance. Hence, it is surprising to find there is very little literature focused on studying this rather obvious effect and its impact on human performance, especially when as much as 60 percent of population has expected some form of sickness from car travel, whereas about a third have vomited in cars before reaching the age of 12 [Griffin, 1990]. To truly achieve the 507 billion dollar target based on work done in automated cars, true human performance under motion needs to be better researched.

A survey conducted by StateFarm in 2016 [Farm, 2016] looked to understand what activities people preferred to do as a passenger in a self-driving car. They reported 45 percent of people would prefer to read texts, 36 percent would prefer to access the internet, 21 percent prefer to watch movies and 19 percent would prefer to read a book; all tasks that are expected to increase motion sickness onset as well as severity. Sivak and Schoettle [2015] carried out a study looking into the likelihood of motion sickness in adults riding as passengers in self-driving cars and found that, 37 percent of American, 40 percent of Chinese and 53 percent of Indian people would experience an increase in the frequency and severity of motion sickness. Modern automakers usually have a large customer base comprising of different demographics. Thus, there is a high chance that certain customers will be much more susceptible to motion sickness than others, making it critical that this response to motion is accounted for across the entire demographic range so that parts of society are not 'designed out' of ownership. [Smyth J., 2018b]

One of the reasons for high incidence of motion sickness is the lack of anticipatory cues (low situation awareness) of the passengers that are engaged in secondary tasks, with regards to the future trajectory of the vehicle. In low levels of automation, situation awareness is a necessity for the successful use of the machine to transport (SAE, 2016). However, in higher levels of automation, situation awareness is still important, especially when drivers are engaged in non-driving tasks. Such users will experience motions that the body won't be expecting since they are not focused on the road. Repetitive exposure to such low frequency motion (especially below 0.5Hz) can induce motion sickness [Turner and Griffin, 1999].

In order to incorporate motion sickness into the design of automated vehicles, we have to study it carefully and look at its possible effects on humans. One way to do this is by studying the effect of sickening stimuli on task performance. Most of previous studies have been done mainly in a nautical context, to combat sea sickness. This report tries to encapsulate the important literature findings relating motion sickness to task performance, in order to find potential sub topics to improve upon.

Chapter 2

Motion Sickness

Motion sickness is a normal, healthy response, albeit ranging in intensity from being just a bit uncomfortable to seriously debilitating. It occurs when people are exposed to unadapted real or apparent motions [Reason and Brand, 1975]. Motion sickness symptoms are consistent over all kinds of motions. Motion sickness can even be induced visually, in the absence of motion, such as when using a Virtual Reality headset.

The effects of motion sickness are known well enough and they usually proceed in an orderly manner. Griffin found that people are usually not aware of motion being responsible for their symptoms and attribute it to other factors such as food, clothing, smell etc. However, literature helps us follow the symptoms of Motion sickness. Benson [1999] found that epigastric discomfort (or stomach awareness) is usually the first symptom. This is followed by increasing discomfort and nausea. Griffin [1990] also found that facial pallor occurs from constriction of face blood vessels and stated other symptoms such as yawning, breathing irregularities, drowsiness, headache etc. This culminates in vomiting. In certain people who are highly susceptible to motion sickness, the symptoms may continue for a few days, reducing their daily performance and well-being [Griffin, 1990].

Griffin [1990] found that there is a wide variation in susceptibility to sickness between people as well as within individuals at different times. Age, sex and physiological states (such as personality, experience, drowsiness etc) play a part in this wide variation, all to different extents.

Age and sex seem to be the most significant sources of variance. [Reason and Brand, 1975] found that children under the age of 2 cannot get motion sick while children under the age of 12 are the most susceptible. After 12, our tolerance gradually builds up with age[Benson, 1999]. This does not mean that elderly people cannot get sick. Likewise, females also seem to be more susceptible than males according to Benson [1999]. Matchock et al. [2008] found that the instability surrounding estrogen during certain times may increase susceptibility in females. Certain studies have also found higher susceptibility in introverts [Kottenhoff and Lindahl, 1960].

Inherent in our attempt to understand motion sickness is understanding the physiology of motion sickness. Literature points that people without a functioning vestibular system cannot become motion sick [Benson, 1999]. Thus it becomes pretty apparent that our vestibular system plays an important role in experiencing motion sickness. Our vestibular system functions as our body's accelerometer and gyroscopes, detecting head and body orientation with respect to earth and generating reflexes to improve our posture control [GUEDRY].

The vestibular system is located in small cavities within each ear. The sensory receptors, namely the otoliths and the semicircular canals are present in this cavity. The otolith senses combined gravito-inertial acceleration in the vertical and horizontal plane. The otolith consists of two sacs called utricle and saccule. These sacs contain tiny sensory hair cells called macula, which deflect when we are subject to inertial accelerations or tilts of the head. This deflection causes neurons to fire and send the deflection signals to the brain where they are interpreted as motion. The semicircular canals consist of three canals, perpendicular to each other and help perceive angular acceleration. Such accelerations cause the displacement of the fluid present in the canals that deflect a receptor organ, sending the signal to the brain helping us interpret angular acceleration. Being bio-transducers, the vestibular system is sensitive to high frequency signals and lacks the wide response spectrum of modern transducers and thus struggles sometimes to perceive complex motions [Griffin, 1990].

To improve perception and reduce erroneous response, the vestibular system works with the visual (low frequency sensor) and the proprioceptive system (which is a part of the somatosensory system) to avoid mismatches and get a complete frequency response over a wide frequency of signals.

The somatosensory system obtains information (both internal to the body and external) about the states of the human body such as position, temperature, movement etc [Dougherty, 2012]. The somatosensory system consists of three systems, namely, exteroception, proprioception and interoception. The proprioceptive system includes pressure sensing receptors in the skin as well as in joints which responds to force. Griffin [1990] states that the proprioceptive system influences the interpretation of the vestibular or visual system and might play a part in motion sickness.

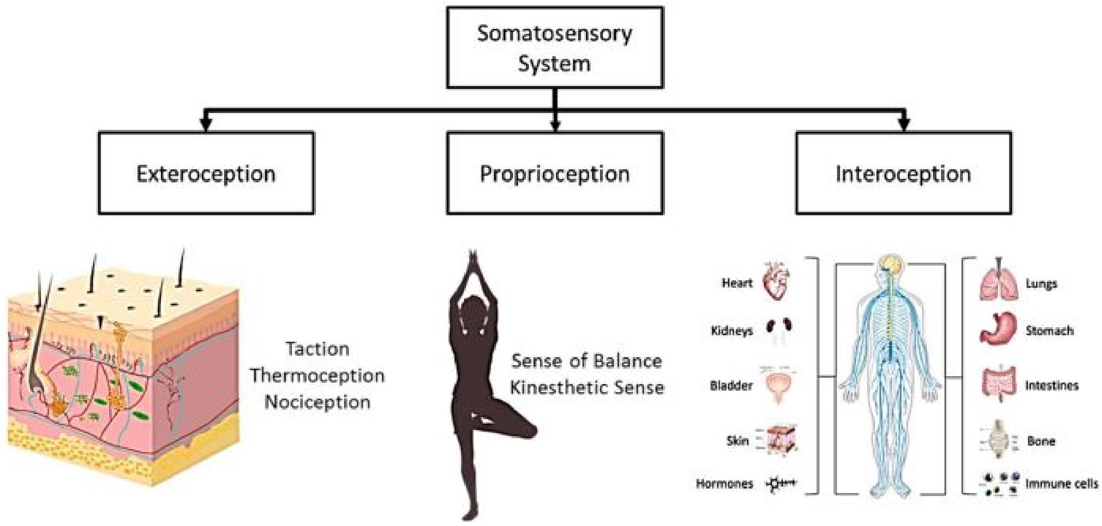

Figure 2.1: Somatosensory system

In summary, the visual, vestibular and proprioceptive systems work together to resolve human motion and orientation as accurately as possible to maintain balance and posture. When these systems obtain conflicting sensory feedback, motion sickness manifests. We now look at some potential theories which explain this mismatch better.
Motion sickness is a complex phenomena that can be caused by a large range of stimulus with no single cause and no simple mechanism, as shown in the figure below from Griffin [1990].

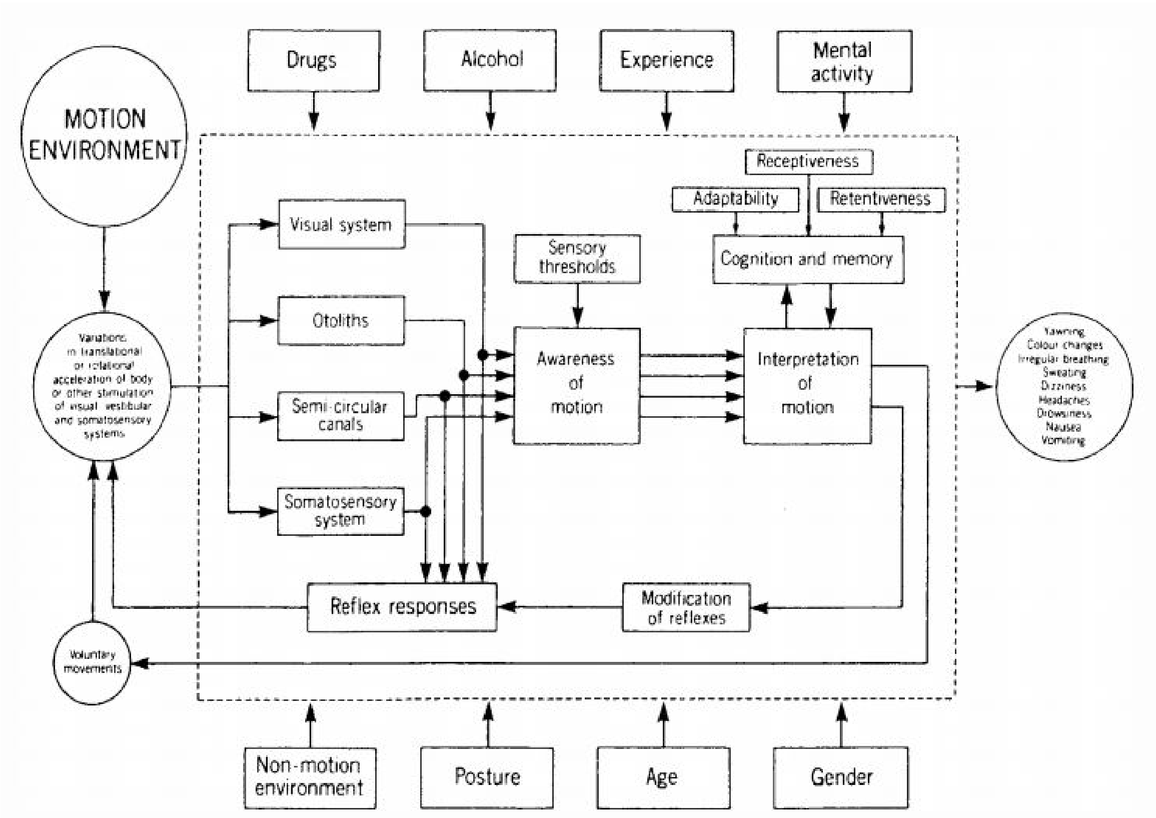

Figure 2.2: Conceptual model of possible factors affecting motion sickness [Griffin, 1990]

Griffin [1990] also stated that several older theories surrounding this phenomena such as blood movement during motion causing motion sickness have been debunked. There are multiple interpretations for why most mammals and even some amphibians develop motion sickness at all. Treisman [1977] found a plausible explanation for the rather crippling experience of vomiting is an evolutionary response to mismatching sensory signals. Abnormal perception of sensory signals (and by extension, the orientation) indicates (to the brain) that the person may have consumed some poisonous substance, resulting in vomiting. Riccio and Stoffregen [1991] on the other hand, suggested that prolonged postural instability is the cause of motion-sickness symptoms. The longer the duration of the instability, the greater the likelihood and severity of symptoms.

Of the various theories trying to explain motion sickness, Reason and Brand [1975] have given the most widely accepted one: The sensory mismatch theory which also has other names such as neural mismatch theory. As explained by Bles et al. [1998], it postulates that motion sickness occurs when there is a mismatch between the pattern of sensory inputs obtained from our sensory organs and the patterns that our mind's forward model expects to get (also known as efference copy). Humans, being adaptive, start updating the forward model to reduce the mismatch error, manifesting itself as the symptoms of motion sickness. This theory is widely accepted since it explains a lot of observations, such as looking at the horizon of the ship reduces error mismatch and hence, reduces motion sickness symptoms.

The sensory mismatch may be either an intersensory conflict or an intrasensory conflict. In intersensory conflicts, incompatible signals are obtained between the visual and vestibular system while intrasensory conflicts are those in which there is a mismatch within the vestibular system, between the otoliths and semicircular canals. Griffin has summarized the possible conflicts in the table below.

Table 2.1: Potential conflicts encapsulated by sensory mismatch theorem[Griffin]

Type of conflict	Inter-sensory (Visual-Vestibular)	Intrasensory (Canal-otolith)
Type I	Visual and vestibular systems give contradictory or uncorrelated information	Canal and otolith give contradictory or uncorrelated information
Type IIa	Visual system signals in the absence of expected vestibular system signal	Canal signals in the absence of expected otolith signal
Type IIb	Vestibular system signals in the absence of expected visual system signal	Otolith signals in the absence of expected canal signal

In an alternative to sensory mismatch theorem, Riccio and Stoffregen [1991] came up with the posture instability theory, which states that prolonged postural instability causes motion sickness. While the sensory mismatch theory describes motion sickness in a perceptual way using sensory organs, posture instability theory looks at the interaction between perception and action. Riccio and Stoffregen [1991] explains it as "the state in which uncontrolled movements of the perception and action system are minimized".
Recent studies have shown that posture instability precedes subjective MS symptoms but are not necessarily the cause of motion sickness[Stoffregen et al., 2000].

Linking the sensory mismatch theory to car sickness, when driving a conventional car for example, drivers are much less susceptible to motion sickness than passengers even though they undergo the same motion [Reason and Brand, 1975]. This can be explained by the fact that drivers are actively controlling the movement of the car and can anticipate the future motions of the car, as explained using the sensory mismatch theorem. When we look at passengers, who possibly have their eyes off the road looking at their phones or books, they are much more likely to get motion sickness because while their visual system implies rest, they clearly feel the forces of the car as it moves, resulting in a type I inter sensory mismatch.

Bles et al. [1998] have found further evidence supporting the above claim. Drivers have been found to tilt their heads towards the centre of the corner whilst leaning. Passengers, on the other hand, have their heads tilted away from the corner centre due to Gravito-Intertial forces (GIF) which are a known cause of motion sickness. This moderating effect of muscle activity (head tilt done by drivers) on motion sickness is explained in the context of the neural mismatch theory below.

Anytime a motor command is initiated, a copy of the same command from our central nervous system (referred to as the efference copy) is sent to a forward model to obtain the expected signal (referred to as the reafference signal). This is then compared to the actual signals obtained from our sensory systems. In case of any mismatch, the forward model is updated with the aim of minimizing such errors and it manifests as symptoms of motion sickness. Drivers reduce this error with their head tilt, thereby moderating the effects.

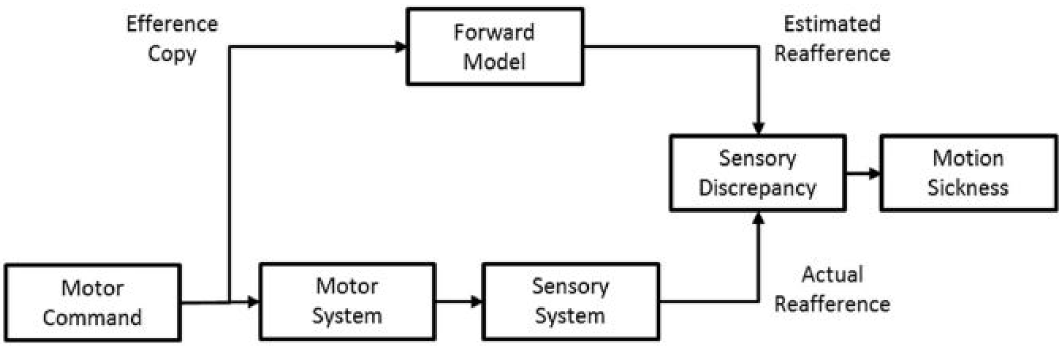

Figure 2.3: Sensory mismatch in block diagram

Mackie et al. [1974] found that the vertical component of motion was primarily responsible for inducing motion sickness, with pitch and roll motions having minimal impact. The maximum sensitivity was found at 0.167Hz of vertical vibrations. Lawther A. however stated that the impact of pitch and roll cannot be discounted.

In cars, low frequency sways (below 1 Hz) start causing mismatch errors in passengers, with symptoms increasing with exposure duration and intensity of acceleration[Turner and Griffin, 1999]. The driving style plays a heavy part in the experienced motions. Griffin and Newman [2004] found that the experienced provocative low frequency fore-and aft and lateral oscillations are more dependent on the driving style than the car design. This might have relevance while designing the sickening stimulus.

To study these symptoms in an experimental setting and compare the severity of the same, we need ways to quantify this effect of motion sickness. This can help us objectively analyze it's effects on passengers and get meaningful correlations.
There are various ways to quantify different aspects of motion sickness that has been used in the literature. Different scales have been designed to assess different aspects of motion sickness: while some assess the severity of sickness at that time, others assess the susceptibility to sickness of people. The choice of measure depends on the type of task the subjects are involved in. A more descriptive measure of motion sickness may require more cognitive effort from participants, potentially affecting their performance but gives us a better insight into the symptoms and thus, a balance must be reached [Dahlman et al., 2009].

Questionnaires are one of the most used methods of obtaining subjective measures of motion sickness in the literature. It relies on humans being able to accurately judge their sickness severity, and a wide range of questionnaires exist to measure this.
Pensacola Diagnostic index (PDI) is one of the most widely used questionnaires for the assessment of motion sickness [Gianaros et al., 2001]. Although used widely, it has a limitation that it gives a single score that depends on the various symptoms of motion sickness, rather than break down the symptoms into its different dimensions and giving individual sickness levels for each dimension.
The Simulator sickness questionnaire (SSQ) is widely used to quantitatively perceive simulator sickness The questionnaire asks participants to score 16 symptoms on a four point scale (0-3). A factor analysis revealed that these symptoms can be placed into three general categories: Oculomotor, Disorientation, and Nausea [Kennedy et al., 1993].
The Motion Sickness Assessment Questionnaire (MSAQ) is a useful tool in the subjective assessment of motion sickness symptoms [Gianaros et al., 2001]. It looks into the different dimensions of symptoms of motion sickness: gastrointestinal, central, peripheral and sopite-related and is a 16-item questionnaire. The scores from the MSAQ correlate strongly with overall scores from the Pensacola Diagnostic index [Gianaros et al., 2001].
Fast Motion Sickness Questionnaire (FMS) is one of the most efficient tools to collect motion sickness related data online and includes a verbal rating scale ranging from zero (no sickness at all) to 20 (frank sickness). It is useful to study the effects of motion sickness with time [Keshavarz B, 2011].
The Misery Scale (MISC) developed at TNO is a 11 point ordinal scale measure in which subjects can give subjective scores on the feelings on misery at a high frequency, allowing for quick online measurement of sickness symptoms [Bos et al., 2005]. By combining the more extensive questionnaires such as the SSQ or MSAQ with shorter and quicker likert scales such as the MISC and the FMS, we can get an insight into the complete dynamics of the symptoms of motion sickness

Motion sickness history questionnaire (MSHQ) [Reason and Brand, 1975] is a quantification which is used on a personalized level, unlike MSI. The questionnaire collects information about past experiences with motion sickness for people. The collective score in MSHQ indicates how susceptible an individual is to a sickening stimulus and can help in the experiment. It is usually done for the pre-analysis of the human subjects taking part in the experiments. Gianaros et al. [2001] found that the MSHQ scores have strong correlations with nausea profile and with Pensacola Diagnostic index.

Depending on the experimental design, a combination of the aforementioned metrics may be used to measure subjective sickness as well as susceptibility to sickness. There is no clear best measure for motion sickness and it really depends on the nature of the research question and the experimental design to choose an appropriate measure.

Chapter 3

Impact of Motion Sickness on Task Performance

Motion sickness has two main detrimental impacts on humans: comfort and performance. In this chapter, we look at the literature to see how performance is affected by motion sickness. Wertheim classified the performance implications based on their actions on humans as general effects and specific effects.

General effects could be effects related to motivation, energy or biomechanical factors that affect performance in humans undergoing motion while specific effects refer to those effects that interfere with abilities specific to each human, such as cognition, perception and motor skills. Thus, any performance decrement due to motion sickness would involve the aforementioned general and/or specific effects.

Stevens and Parsons [2002] state that "motivational effects refer to the psychological and physiological responses to a provocative motion". A combination of drowsiness, nausea, sickness and apathy negatively affects motivation to complete a task. They have also stated that even severely sick individuals can continue to carry out tasks essential to their survival, which suggests the important role motivation might play in performance under motion sickness.

Energy effects are seen in motion induced fatigue, which is commonly experienced at sea. The extra effort required to maintain one's balance often increases fatigue and decreases mental effort thereby reducing human performance. This is more relevant for ship research because ships are minimally manned these days and hence, it is essential that crew performance never drops below a certain threshold.

Biomechanically, any motion environment may interfere with the human's own motion required for any task. A Motion induced interruption (MII) is defined as "an incident where ship motions become sufficiently large to cause a person to slide and/or lose balance unless they temporarily abandon their allocated task to pay attention to maintaining correct posture [Crossland and Rich, 2000].

Crossland and Rich [2000] also stated that MII includes three phenomena, that is,

1) Stumbling due to momentary loss of posture stability.
2) Sliding due to slipping of foot on moving surface
3) Complete liftoff when motion forces exceed the force of gravity.

As explained by Stevens and Parsons [2002], specific effects of motion sickness refer to the effects motion sickness has on specific human abilities or skills, such as cognitive tasks(attention, memory and pattern recognition), motor tasks(manual tracking, fast button press reactions), perceptual tasks(visual or auditory detection) etc.

Cognitive tasks are those tasks requiring attention, memory and pattern recognition. Tasks that passengers are expected to do in automated cars, such as reading, writing an email or attend an online meeting, require human cognitive abilities such as mathematical reasoning, verbal comprehension, perception etc. Thus, this is an important specific effect of motion sickness on humans, which is also evident in literature.

Motor tasks refer to tasks including manual tracking and/or button pressing. They vary depending on a few factors such as: Severity of motion, weight and complexity of the motor task to be done as well as individual experience. This has relevance in level 3 automation where the driver is handed over control at different times.

Tasks that require visual or auditory signal detection come under perceptual tasks. Almost every human task includes perception, including driving and walking. Thus, it is important to look into if and how motion sick-

ness degrades perception of humans to avoid potential accidents.
We thus see that task performance might be affected by a combination of general (such as motivation and willingness to do the task) and specific effects (cognitive, perceptual and/or motor performance decrement). We look into the existing literature to study this in more detail.

3.1 Literature on motion sickness's impact on performance

The impact of motion sickness and the general as well as specific effects associated with it must be studied in order to gain better insight into the underlying phenomena and to predict human performance. We look at a few studies that have explored the aforementioned area and try to gain some insights.
The classic studies in this field were focused on the maritime industry for combating sea-sickness and it's impact on the limited workers on the ship with Wertheim [1996] studying the impact of sea sickness on a complex task design The tasks were meant to model a simple but realistic naval tasks, including decision making based on radar images and memorizing the information The tasks involved cognitive, perceptual and fine motor skills. They observed a small but significant reduction in information transfer. However, Wertheim [1996] noted that the results were not generalized enough to extend to other fields. The reduction in information transfer could not be attributed to just cognitive or perceptual skill loss. A better alternative would be to look at basic tasks underlying any complex task such as only cognitive tasks. However, this study did show an impact of motion on human performance. The next step was to find out how motion sickness affected each basic task and trying to find generalizable results.

Cowings [1999] focused on the performance of soldiers in command and control vehicles in the military. A large numer of tasks performed by soldiers in such vehicles are not directly related to vehicle operation, but are involved in uncoupled tasks such as controlling a drone, finding a target location on a map etc. To assess task performance under sickening conditions Cowings [1999] measured perfomance over a wide array of tasks, including; three-choice reaction time, code substitution, pattern comparison, preferred hand tapping, non-preferred hand tapping, grammatical reasoning and spatial transformation. Investigators found reduced cognitive and motor skills of the subjects in the vehicle. They also took a subjective scale called the mood-sleep scale which tries to quantify the general effects of motion sickness. The mood-sleep scale is divided into activation mood dimension (which measures the readiness to perform) and the affective mood dimension (which measures the self-perception of readiness). This scale looks to quantify the general effects of motion sickness such as motivation, arousal, sleepiness etc. Analysis showed that the mood states were degraded in the vehicle in all conditions compared to baseline stationary condition(chi square = 50.4, $p < 0.000001$) and thus, the general effects of motion sickness was also visible during the motion condition of the vehicle.

Following up on command and control studies, Muth et al. [2006] looked into the reduction of performance when undergoing uncoupled motion along with the effect on motion sickness symptoms. Commonly experienced uncoupled motion, for example, is when an individual is exposed to one real motion while simultaneously is exposed to a separate virtual motion (eg. playing a video game in a moving vehicle). They found that time for task completion was significantly longer in the motion condition than the stationary condition, $t(9) = 1.96$, $p < .05$. They also found that task accuracy was significantly lower in the motion condition, $t(9) = 3.73$, $p < .05$. MSAQ ($t(9) = 3.37$, $p < .05$). They also found that the SSQ($t(9) = 3.30$, $p < .05$) scores were significantly higher for the motion condition than the static condition. The tasks used for measuring performance in this study was the microsoft xbox console and the game chosen was Project Gotham 2 driving game and the results show a clear decrements in performance. We can also see that video games provide a good model to measure task performance. The task used here seems to be a novel enough task. Hence, motivation is not expected to be the bottle neck in this case. The sickness scores on average never crossed the threshold that is considered as motion sickness territory, and hence, these performance decrements occurred without true motion sickness. Since the controller was an actual steering wheel complete with foot pedals, there would have been significant bio dynamical interference between the actual vehicle motion and the participant's controlling ability, Navigating through the cones required the fine motor skills of moving the steering wheel and perhaps the motion of the real vehicle directly affected the control of the game of the participants. Finding tasks that reduce this kind of interference and are exclusive of other areas of task performance would give clearer results.

There are multiple studies on the effect of platform motion in the maritime industry on sickness [Donohew and Griffin, 2004], [Golding et al., 2001]. However, these studies ignored the impact of vision in the study. To bridge this gap, Bos et al. [2005] studied the effect of vision on motion sickness in a naval setting with 24 subjects. Thus, the integration of various sensory signals (including vision) and its impact on motion sickness was studied properly here. Perhaps the findings are transferable to a driving scenario, where, anecdotally, looking outside the car window helps in reducing motion sickness. He used three experimental conditions, namely OUT (with an out the window view), IN (with no outside view) and Blindfolded and looked at task performance in the presence of sickening stimulus. Motion sickness was recorded on the MISC scale to track the development of sickness. The task given was to recollect a set of words presented on the screen (and via audio for the blindfolded participants). MSSQ scores were collected during pre-screening. Significant correlations were just observed for the Blindfold condition (p=0.045) with a negative correlation (r=-0.41) implying a reduction in errors with increased sickness. Further, there was a large variability in performance in the blind condition. The results are surprising, and perhaps the sickening stimulus was too mild and habitation was rather quick in the blind case. Another possible issue could be the type of task used, since there was a high chance of misinterpreting the word heard via headphones in the blind case. When looking at the MISC ratings, the IN condition showed the worst symptoms, followed by OUT and Blindfolded condition, with the latter being the most comfortable. Bos et al. [2005] arrived at the conclusion that no systematic reduction of task performance was observed with increasing sickness using the aforementioned task. Reason and Brand [1975] have stated that not only does motion sickness affect task performance, but the otherway around is also a possibility, and Bos et al. [2005] suggests that this might be the case here. The task perhaps, being novel, helped the participants suppress their sickness symptoms and they did not lose motivation to complete the task. The exact impact of motivation and potential interference with cognitive task performance is not looked into here. The grouping, which was done based on motion and no-motion condition also seems to be an inaccurate classification method since there is a lot of variability in these conditions.

Some commonly observed signs and symptoms of motion sickness are irregular breathing, yawning, sweating, drowsiness, facial pallor, nausea and emesis. Graybiel, A., & Knepton [1976] defined the term 'sopite syndrome' to study the effect of motion sickness in better detail. Sopite syndrome describes drowsiness, yawning, lethargy and laziness among other mild symtoms related to motion sickness. The impact of sopite syndrome on human performance was not well explored before the following study, especially when that state is commonly experienced by humans undergoing motion. Infact, depending on how susceptible each individual is, sopite syndrome might be the only manifestation of motion sickness in them [Graybiel, A., & Knepton, 1976]. Matsangas and McCauley [2012] studied the effects of mild motion sickness and sopite syndrome on multitasking cognitive performance with 51 participants. The tasks that the participants were to do included 4 sub tasks under the SYNWIN multasking battery[Elsmore, 1994] to be done simultaneously: a memory search task, an arithmetic problem task, a visual and an auditory reaction task all presented on the same screen divided into 4 quadrants. Proctor et al. [1998] found that the four generic SYNWIN tasks constitute the fundamental tasks that we find in our work cognitively. The memory and arithmetic tasks correlate to working memory [Raghubar et al., 2010]. The perceptual visual and audio tasks help us assess distinct attentional resources[Wickens, 2002]. They analysed susceptibility using a revised MSSQ while severity of symptoms was assessed using MSAQ. They further analysed soporific severity using the Stanford Sleepiness Scale [Shahid et al., 2011] to observe effect of sleepiness on alertness since drowsiness is also a general effect of motion sickness. The participants were classified into two motion sickness groups, that is, symptomatic and asymptomatic, to compare average participant symptom severity for both conditions. Subjects were classified as symptomatic if their symptoms was greater in the motion condition whereas for asymptomatic, no sickness symptoms were found in either condition. Matsangas and McCauley [2012]found that cognitive multitasking performance dropped even in the presence of mild motion sickness. Performance differences between symptomatic and asymptomatic were: 9.43 percent for composite scores, 31.7 percent in memory tasks and 14.7 percent in arithmetic in the favour of asymptomatic subjects. Thus, these tasks are definitely affected by motion sickness. In the first session, participants seemed to overcome sickness symptoms whereas in the second session, motion sickness affected task performance. Matsangas and McCauley [2012] provided a conceptual description of multitasking performance in the diagram below.
Significant differences in performance as well as subjective sickness symptoms were found based on the grouping of symptomatic and asymptomatic participants. Thus, this distribution is definitely better than the distribution based on motion and no motion, with lesser variance in the former distribution. This study also gives a better insight into the impact of motivation on task performance. A novel enough task can bring about motivation in participants where they suppress their sickness symptoms and carry out the task at hand, such as in the first motion condition in this study. By the second study, task novelty had worn off and performance decrements were observed. The authors also explored the concept of motion sickness acting as a stressor and thus causing performance decrements, but further study is recommended.

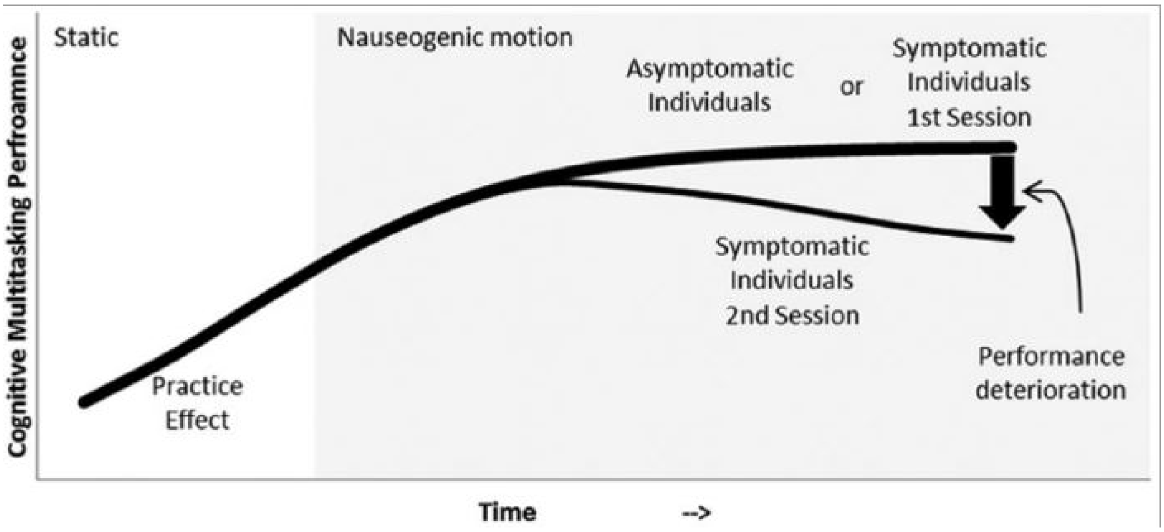

Figure 3.1: Conceptual depiction of multitasking performance versus nauseogenic motion stimulus, motion sickness severity, and experimental session [Matsangas and McCauley, 2012]

Dahlman et al. [2009] studied the effect of motion sickness on short term memory and on autonomic responses on 38 healthy participants. Physiological responses were also recorded. These included; heart rate (HR), skin conductance level (SCL) and blood volume pulse (BVP). Motion sickness was induced with an optokinectic drum being rotated at a velocity of 10 rpm for a maximum of 25 minutes. Dahlman et al. [2009] states that when using a visual stimulus, performance should be measured with a non-motor cognitive activity. The Borg CR10 scale was used to assess sickness symptoms in subjects in real time due to the speed at which it can be administered as well as its high positive correlation to other extensive sickness questionnaires. The verbal task using in this study was a modified extended version of the listening span test [Daneman and Carpenter, 1980]. In this study, the participants were classified into two groups, the non-termination group (NT) and the termination group (T) to compare performance scores. This classification is based on the fact that the T group's perceived motion sickness developed in an expected manner and they could not endure the entire 25 min stimulation. The NT group's borg scores leveled out over time and their symptoms were not expected to increase even if stimulation duration was further increased. Here too, we see a similar grouping as Matsangas and McCauley [2012], but done in a single experiment. This was done by using a stronger sickening stimulus. The group effect was significant, $F(1,47) = 58.0$, $p<0.001$ indicating significantly higher sickness severity in the T group. Similar trend was found when studying interaction effect, $F(2,48) = 35.4$, $p<0.001$ implying that the change in perception of sickness symptoms while undergoing motion was very different in the two groups. Baseline short term memory (STM) performance did not differ significantly between the two groups, with the largest difference between the groups in number of correctly recalled words seen in the last minute of the test, with reduced STM performance from the T group and an increased STM performance from the NT group with an estimated mean difference of -11%. The performance of both groups proceeded similarly till the mid point, after which the aforementioned differences can be seen clearly. Dahlman et al. [2009] further tried to assess whether the performance decrement was due to loss of motivation or high levels of sickness symptoms. The borg scale ratings show that the T group was experiencing really strong motion sickness before termination (mean score = 7.9) implying that the performance decrements were likely due to high perceived sickness. Bottomline is, performance was not successfully attributed to a confounding effect of motivation and cognitive decrements and the performance effect size is not clear until the last minute of the experiment.

We now review a couple of papers that looked into the domain of simulator sickness and explored the fidelity of the sickness symptoms with respect to actual car sickness. Smyth J. [2018a] found that there is limited understanding of what areas of human performance are affected by motion sickness and that past studies relied on their "industry-specific, non-standardized and non-repeatable measure of performance". Focused on the 'transferability' of experience and performance from a simulator to a real vehicle, they found it imperative to first understand to what extent motion sickness affects performance, before looking into the fidelity of simulators in this aspect. Smyth J. [2018a] looked at three key areas of performance of a driver: physical, cognitive and visual as well as their intersections as shown in the diagram below. They believe that the six areas shown below likely cover all possible human interaction at its core.

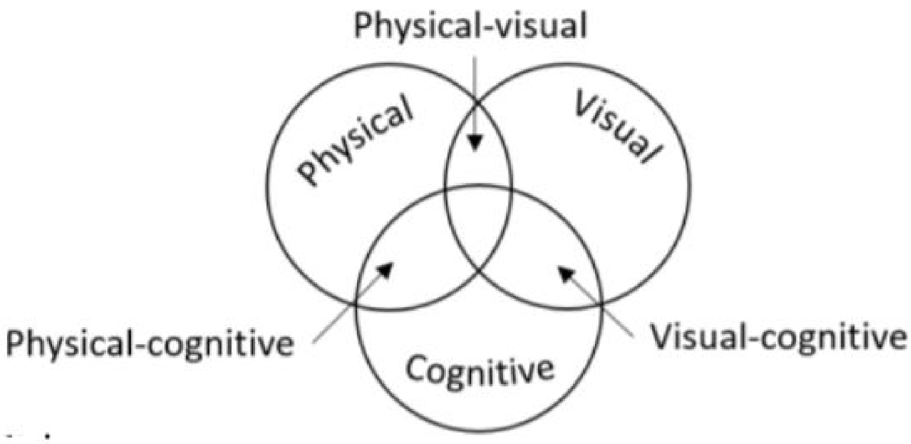

Figure 3.2: Task performance diagram [Smyth J., 2018a]

Smyth J. [2018a] chose tasks that were pre-validated and standardized, took less than a minute to complete, showed no learning effects (performance unaffected by repeated exposures) and represented that area of task performance as independently from other areas as possible. Each participant underwent the simulator run for 30 minutes doing the six tasks while rating their motion sickness every minute using the fast motion sickness questionnaire [Keshavarz B, 2011]. Participants also filled out an SSQ on their perception of Motion sickness while completing the six tests. They again completed the tasks after the simulator run for comparison purpose.
For the visual performance, a visual acuity ETDRS LogMars test chart [Smyth J., 2018a] was used where participants, using their dominant eye only and from a pre-set distance, read out letters presented on the chart and scored accordingly. For the physical performance an adapted version of the 'Jebson Taylor hand function test' was used to measure physical skill and dexterity[Raad, 2012]. The scoring was done based on the time taken to turn over all the cards using the dominant and non-dominant hand independently. For the cognitive performance, a 'Paced Visual Serial Addition Test(PVSAT) was used, adapted from an n-back test [Kane M. J., 2007]. Participants were presented with numbers on a screen where they had to add the presented current number to the previous number and give it verbally, with the score based on the correct answers given. For the visual-cognitive performance, a mental rotation test [Peters M., 1995] was used whereby participants had to identify which side views (from an option of 4) corresponded to a 3D target shape. Scores were based on accuracy and completion time. For the physical-visual performance, the perdue pegboard was used for assessment. It involves identifying and locating pins in small holes with both the dominant and the non-dominant hand, testing both physical dexterity as well as visual skills. For the physical-cognitive performance, a reaction time test was used where participants had to identify a correct stimulus from a set of visual stimulus; in this case, a traffic light, by pressing a physical button. This test analyses both the cognitive speed as well as the physical response time.
23 participants (45 percent) ended the early study due to motion sickness and were classified as 'dropouts'. They found significant effect size on the dropouts for nausea scores ($F=0.697$, $p>0.05$). Again, this is analogous to symptomatic and asymptomatic classification is a much better grouping method as compared to the simple motion and no-motion condition. On analysis of the SSQ scores between the dropouts and the rest, significant difference in mean scores of SSQ 'total'($F=14.135$, $p<0.001$), 'nausea'($F=19.624$, $p<0.001$) and 'disorientation'($F=15.556$, $p<0.001$) was found. 'Ocularmotor' mean scores between the two groups did not differ significantly ($F=1.570$, $p>0.05$). The methods of measuring sickness, namely SSQ and FMS, had significant correlation when looking at the participants who completed the driving task ($r=0.620$, $p<0.001$) which implies that FMS is indeed a decent and quick way of measuring subjective sickness, similar to the borg scale used in the previous study.
Looking at visual performance, no significant effect of motion sickness was observed on it in this study but future studies could look at visual acuity. In the physical test, it was found that people were slower at these

tasks after using the simulator. Significantly worse performance was observed in the dropouts, for both dominant as well as non-dominant hands, implying that MS worsens physical performance, especially for symptomatic participants. Looking at the cognitive test, significant negative effect of Motion sickness was found on cognitive skills of the dropouts after driving than before. However, there was no significant difference in the scores of people who completed the study, implying the simulators don't negatively affect cognitive performance. Interesting results were found for the visual-cognitive test, where performance on average, increased after people completed driving the simulator, implying that driving simulators can improve spatial abilities. No significant differences were found in the two groups, and is a potential area to explore. Looking at visual-physical performance, the analysis showed that MS seemed to affect only the dominant hand performance, which is interesting. Finally, looking at the cognitive-physical scores, significant differences for both groups in reaction time scores was found. The whole group average reaction time was also higher, implying the driving in simulator affects cognitive-physical skills, in this case, reaction time. Here, the distribution is done based on those who completed the task and those who couldn't. Similar trends have been seen in previous studies as well. This binary method doesn't let us look into group dynamics, where there could be significant variation in sickness severity within group. However, the authors found that there currently exists no validated methods of categorizing severity into reasonable groups and is a potential area of further improvement.
The previous study showed that Motion sickness had a negative impact on certain areas of the essential task performances. In a follow up study to the previous one, Smyth J. [2018b] studied the impact of the extent of severity of motion sickness on the extent of severity on human performance in the context of automated cars using a simulator study design on 51 participants. They tried to assess whether the intensity of motion sickness was a good predictor of the reduction/degradation of human performance. They observed that for the tasks chosen, the effect of motion sickness on human performance,was for most part, independent of subjective MS severity, indicating that reduction in task performance is similar for minor as well as, severe levels of motion sickness. This is contrary to the expectations of Smyth J. [2018b] which was that the effect of motion sickness on task performance would scale with its severity, with more sick participants having a higher decrement in overall performance. However, we see that the scale of the effect of sickness symptoms has a great variance between participants where the range of performance scores seen are largely independent of the SSQ total scores in this study. A possible area to look into would be finding a more accurate measure of perceived motion sickness, since humans have limited ability to accurately rate their sickness symptoms.

Certain observations become apparent based on the available literature on Motion sickness.
In the studies where a drop in task performance is seen after motion, it is attributed to the specific effects, namely cognitive, motor and/or perceptual skills decrements. However, when this drop in task performance is not very clear, it is assumed to be so due to high task novelty, where the general effect of lack of motivation is overcome by the participants. It seems that when participants are motivated, they manage to overcome the specific effects as well. However, the impact of this general effect of motivation on task performance during motion sickness has not been explicitly studied, and has always been a part of the discussions after the results are obtained.
Secondly, in the aforementioned studies, the complexity of the task is always fixed. Task performance is then coupled to either the speed of response (via reaction times) or the accuracy of response (number of correct responses). Reaction time tasks look at our cognitive processing speeds while tasks measuring our response accuracy are dependent on the given task complexity. Certain studies have also linked easy tasks, such as reaction time tasks, as tasks that lack novelty which partially explains certain confounding results obtained where the expected drop in task performance is countered by motivation to complete the novel task. Perhaps choosing tasks with varying difficulty level can give us further insight into the cognitive processes involved and the respective decrements associated with each difficulty level. However, it must be remembered that not every difficult task is necessarily a novel task, that is, task difficulty need not be a predictor of task novelty.
Thirdly, most of the studies have chosen tasks that model the various potential passenger tasks, such as arithmetic tasks, perceptual tasks and motor tasks. However, one very obvious class of tasks that passengers are expected to perform, namely reading comprehension, have not been explored in the setting of motion sickness at all.
Fourthly, the distribution of the control group and experimental group in very early studies was based on 'motion' and 'no-motion' condition to compute performance decrements under sickening stimulus. However, the group distribution was not perfect, with lot of variation within each group. Matsangas and McCauley [2012] then came up with the symptomatic and asymptomatic group distribution which showed a greater effect size than the previous distribution. This grouping still is not perfect with often confounding results within each group. Perhaps a better grouping method could help us model motion sickness with greater ac-

curacy.
Another observation in the studies is for the asymptomatic participants. Their behaviour and performance was more or less consistent, with symptoms levelling off and performance not being affected with increasing duration of stimulus. Thus, when trying to study car sickness, it makes more sense to only look at the behaviour of symptomatic participants since these are the people who will be adversely affected by motion sickness and are more likely to not accept the setting commercially.

3.2 Research Question

Trying to fill the existing gaps, we found that Nourbakhsh et al. [2012] successfully used two categories of tasks, namely Arithmetic and Reading tasks with varying difficulty levels to study whether galvanic skin response was a good indicator of cognitive loads. Our focus is on the tasks used, since tasks with changing difficulty levels have not been used in motion sickness studies. Further, reading tasks have hardly been explored in the context of motion sickness, which makes this study rather interesting. For the arithmetic tasks, the experiment involved 8 arithmetic tasks with 4 difficulty levels (2 tasks per difficulty level). First to fourth difficulty level included binary (0 or 1), one, two and three digit numbers respectively. In each task four numbers were shown one by one, for 3 seconds each. Subjects were to add the 4 numbers and select the correct answer from an option of 3 answers. Performance was attributed to task accuracy here which is a function of task difficulty, rather the speed of response. Similarly, three reading tasks were performed, with each task consisting of 4 slides presented for 30 seconds each. Participants were asked to find words of certain lengths in each slide. There were three difficulty levels: the easiest level included finding three letter words, the medium level included finding three and four letter works while the hard difficulty level included finding three, four and five letter words. They were to click on the left, middle and right mouse buttons on finding a three, four or five lettered word respectively. Using such tasks can help us study the impact of motion sickness on task performance with varying task difficulty levels.

In a study carried out by Guthrie et al. [2006], they looked into the effect of stimulating tasks on reading motivation and comprehension. Both motivation and reading comprehension are potential topics to explore in the context of motion sickness as discussed earlier. We focus on the motivation aspect here, with the hope of using the concepts as a part of our design. Extrinsic motivation can be provided in our potential experimental setting by using extrinsic rewards such as meal coupons or cash for reading [Nolen and Nicholls, 1994]. Intrinsic motivation can also be given for reading comprehension. Guthrie et al. [1999] found that reading motivation does play an important role in reading comprehension, albeit from a children's perspective. This can help us in studying the impact of motivation very clearly on reading comprehension tasks in a motion sickness setting by providing motivation to one group and no motivation to the other group for the same task.

With that, we arrive at two possible research questions.
1) What is Impact of motion sickness on reading task performance of varying difficulty levels.
2) What is the interaction and impact of motivation and motion sickness on cognitive performance in reading tasks.

It would be interesting to look into the role motivation plays on task performance under motion sickness to help design the kind of tasks to be given to the passengers. Further, if motivated human performance indeed does not degrade even when motion sick, it would have interesting implications on the kind of tasks humans will be expected to do when undergoing motion.

Thus, we decide to explore the 2nd possible research question:What is the interaction and impact of motivation and motion sickness on cognitive performance in reading tasks. We also factor in workload, perceived sickness and perceived motivation into our study for a more robust design.
Following the research question, we hypothesize the following statements:
1) Designed Motivator improves task performance
2) Designed Motivator reduces perceived motion sickness level
3) Designed Motivator reduces perceived workload
4) Designed Motivator increases perceived motivation
5) Motion reduces task performance
6) Motion increases perceived motion sickness level
7) Motion increases perceived workload

8) Motion reduces perceived motivation
9) Impact of motion on task performance is lesser in the presence of designed motivator
10) Impact of motion on perceived motion sickness level is lesser in the presence of designed motivator
11) Impact of motion on perceived workload is lesser in the presence of designed motivator
12) Impact of motion on perceived motivation is lesser in the presence of designed motivator

Part II

Experiment Design

Chapter 4

Experimental design Overview

From a full factorial design perspective, we have a total of 4 condition to be tested for the reading comprehension task, namely
1) No motion condition without motivator (control condition)
2) Motion without motivator
3) No motion with motivator
4) Motion with motivator

We attempt to look at how our independent variables, namely the designed motivator and motion affect cognitive (task) performance, perceived workload, perceived sickness level and percieved motivation in order to test our hypothesis. Condition 1 and 3 will let us look into the impact of our motivator on task performance without the interference of motion. The data obtained here will let us check whether the kind of motivation we provide is suitable for the task and/or the participant group. Once we know the impact of motivation on task performance, we can then look into how motion and our motivator interact with task performance in condition 2 and 4.
To this end, we use a within-subject design, where the participants undergo all 4 conditions and their performances are compared with themselves. The statistical power of a within-subject design is usually greater than between-subject design since participant behaviour are usually consistent with themselves across the different conditions [Winter, Joost C F De Dodou, 2017]. Consequently, this kind of a design also requires much lesser participants since each participant acts as their own control [Winter, Joost C F De Dodou, 2017]. However, since each participant undergoes all 4 conditions, possible order effects such as practice, fatigue and carryover effects may arise. We use counter-balancing to counter such order effects. We may use complete counter-balancing which balances out each and every possible order. For our study with 4 conditions, complete counter balancing would yield 24 possible orders [Underwood, 1949] which would require at least 24 participants. Winter, Joost C F De Dodou [2017] state that a Latin Square can be used to generate a workable number of orders to be balanced, where each condition appears exactly once in each row and column which is what we go for. The latin square has a drawback that each condition is surrounded by the same pattern of conditions implying that not all order and carryover effects can be ruled out unlike complete counterbalancing [Winter, Joost C F De Dodou, 2017]. However, it is a lot simpler to implement into an experiment when participants available are limited. The exact order will be decided based on how the cognitive task is set up.

We now move on to finalizing the experiment design, namely the type of motivation provided, the task given to participants, the motion profile design, the questionnaires to be administered, recruitment of participants and the Order in which participants undergo each condition.

Chapter 5

Independent variables Design

First up we look into the design of our two independent variables, namely motivation and motion.

5.1 Motivator

One of our independent variables is our Motivator, and it is crucial that we choose the right kind of motivator. For this, the motivator we choose must be simple to provide, easy to measure and applicable to all participants.
The Self-Determination theory [Deci and Ryan, 2008] is a broad theory that specifies the different kinds of motivation. Broadly, Intrinsic motivation helps an individual to gain "inherent satisfaction" from the behaviour and the reason for engaging in the activity is for the experience whereas Extrinsic motivation is when the source of motivation for engaging in an activity is an external agent [Deci and Ryan, 2008]. This theory best explains all the aspects of motivation.
According to Deci and Ryan [2008], an overwhelming majority of human behaviour cannot be intrinsically motivated. Several self determination theorists such as Gagné and Deci [2005] have recognized that intrinsic motivation is not a realistic goal for many applications. Extrinsic motivation, on the other hand, exists in four forms based on the degree to which behaviour is automated and the goal is in line with the person's values. The figure 5.1 summarises the types of motivation.

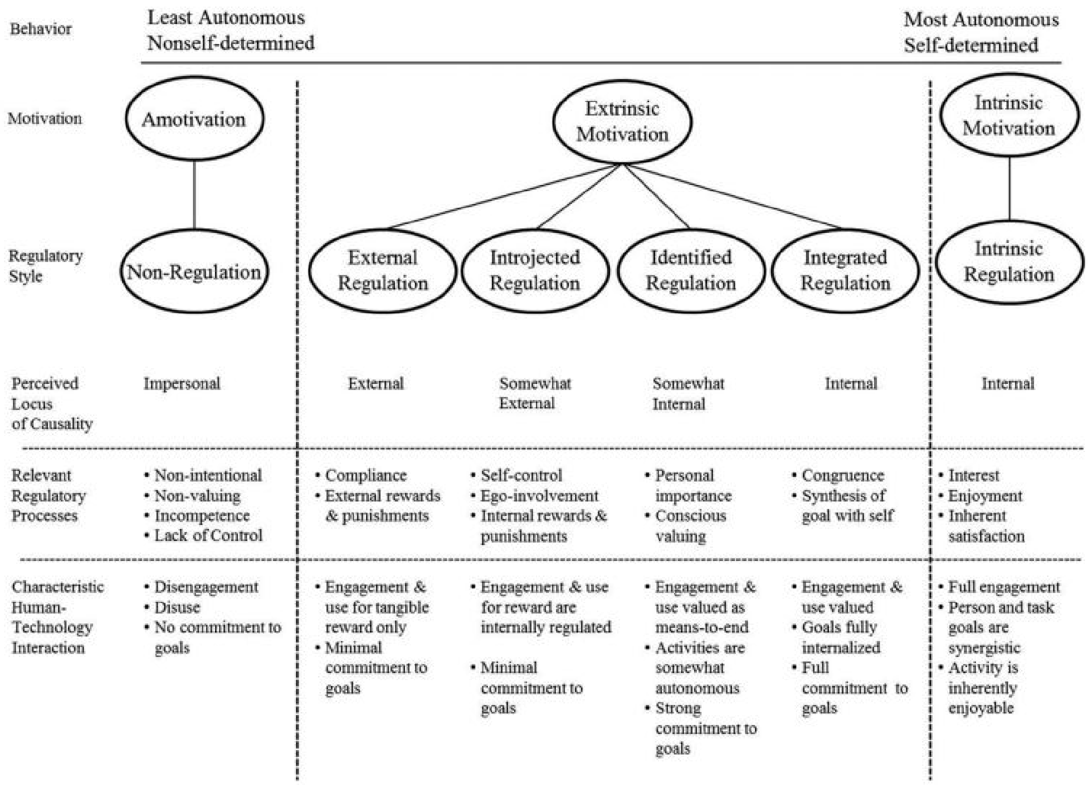

Figure 5.1: Types of motivation based on Self Determination theory [Ryan and Deci, 2000]

Motivation is a way to increase task engagement, and to that end, it has been found that reward-based systems can be appropriate to engage people in short-term activities or to teach people valuable skills [Nicholson, 2013]. Reward based motivation comes under external regulation. Our experiment sessions, being short term activities, would benefit from this kind of a reward based motivation approach.
Thus, Motivation is provided in an extrinsic manner (incentives of either cash or coupons) in two possible ways:

1) Score based reward: This will motivate the participants to answer the questions, and more importantly, answer them correctly rather than guess their way through.

2) Time based reward: This will encourage participants to finish the complete set of tasks and perhaps also motivate them to endure their sickness symptoms for longer. On the downside, they might guess their way through since no weight is put on the accuracy of responses which is undesirable.

A score based reward structure is selected since we do not want participants to simple endure the stimulus but to also perform the cognitive task accurately.
A second kind of motivation was also chosen to be provided, namely competition. Franken and Brown [1995] found that competition increases intrinsic motivation as well as integrated regulation, and to that end, we decided to combine the two kinds of motivation in the hope that it motivates a larger subset of our participants, and to cover larger ground in terms of motivation.
Thus, for the reward conditions, participants will be ranked based on their total score which shall be revealed to them to impart competition based motivation. The top 3 ranked participants for the motion conditions will be given a coupon worth 50 euros, 30 euros and 20 euros respectively to impact external regulation based motivation. We further interact with participants for both the motivation and the no-motivation condition in the exact same way apart from the information on the reward system to minimize uncontrolled extrinsic motivation. Friends of the researchers are excluded from the participant pool to further minimize uncontrolled intrinsic motivation and the motivation variable is finalized.

5.2 Motion

Next, we look at the motion profile that the participants experience during the motion condition. The study is decided to be a simulator based one rather than in an actual car travelling on the streets to enhance safety and associated convenience of carrying out the task. The E2M EM6-670 simulator in the vehicle engineering was chosen for conducting sickness studies. One limitation of the simulator that is incorporated into our study is that the motion platform would be limited to motion in only two translational axes, fore and aft motion (x-axis) and lateral motion (y-axis). To this end, the motion variable must fulfill certain criteria: -
1) The motion profile along the x and y axis should produce enough level of sickness in participants. Being a 60 min study, a MISC of 7 or 8 by the end of the study would be appropriate.
2) While generating sickness in participants, the simulator should be within work-space limits to avoid damage to the actuators.
3) The motion profile should try to imitate the motion of a real car, within the limits of the simulator.
4) The motion profile should not be predictable by the participants, and should appear random.

To this end, the acceleration data was collected from an accelerometer in a car during a run through traffic in the Hague, Netherlands. The path was chosen with sufficient turns and stop and go traffic to realistically simulate a car's motion.

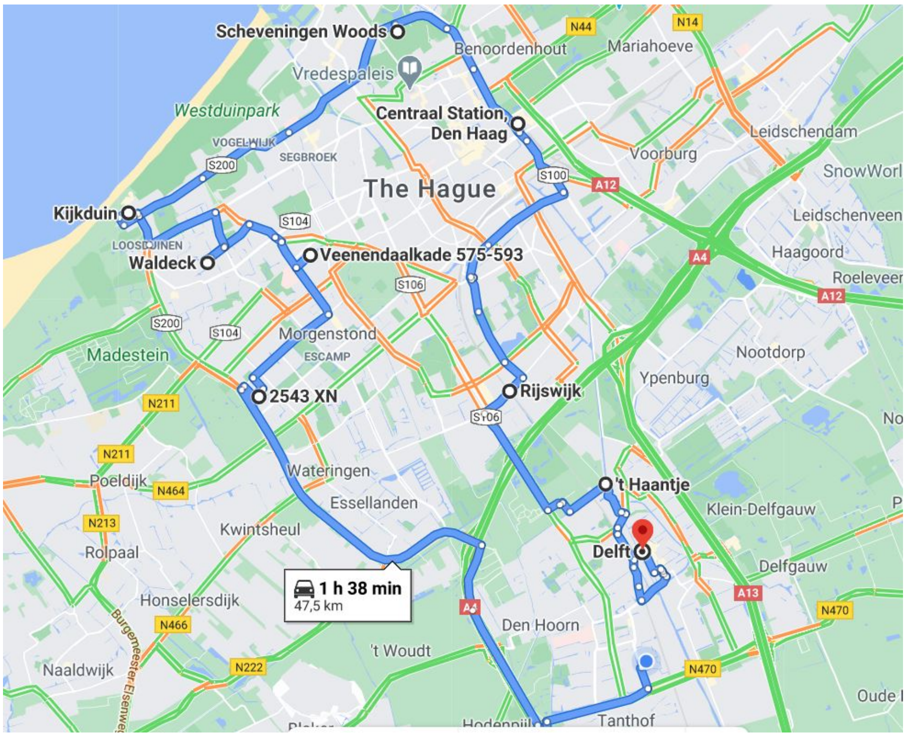

Figure 5.2: Real acceleration data collection route

A 40 minute section of data was analyzed, both in time domain and frequency domain. For the initial analysis, we analyze all 6 degrees of motion to study the sickness dynamics associated with an actual car's motion in detail.

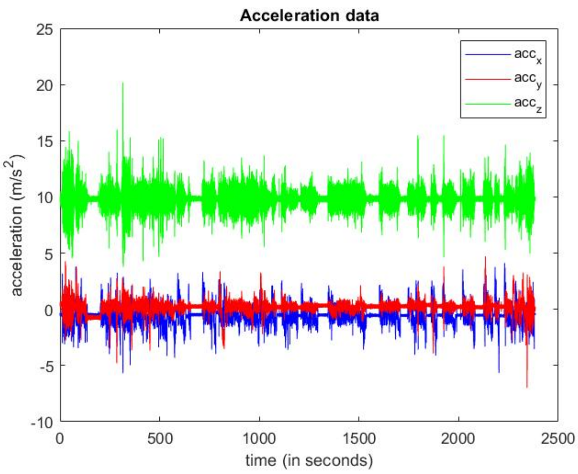

Figure 5.3: Translational accelerations

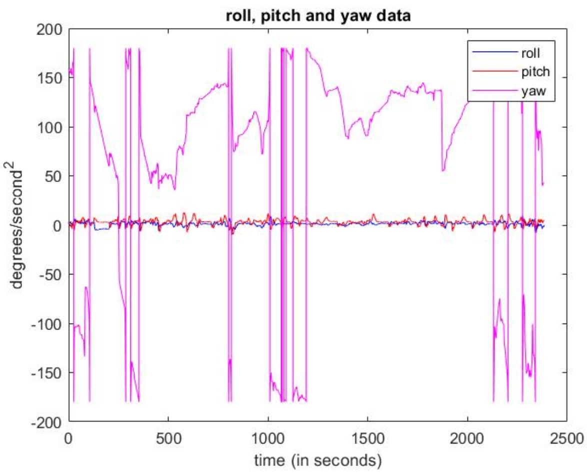

Figure 5.4: Rotational accelerations

The time domain analysis reveals rather little about the data. We can see that the fore and-aft as well as lateral accelerations are centered around $0m/s^2$ while the vertical accelerations are centered around $9.8m/s^2$, courtesy of the gravitational acceleration. Likewise, the roll and pitch accelerations are centered around $0degrees/s^2$ while the yaw varies quite a bit owing to the car taking turns on the road. We now look at the X and Y acceleration data in the frequency domain to get some more insight into the motion characteristics that we want our simulator to reproduce.

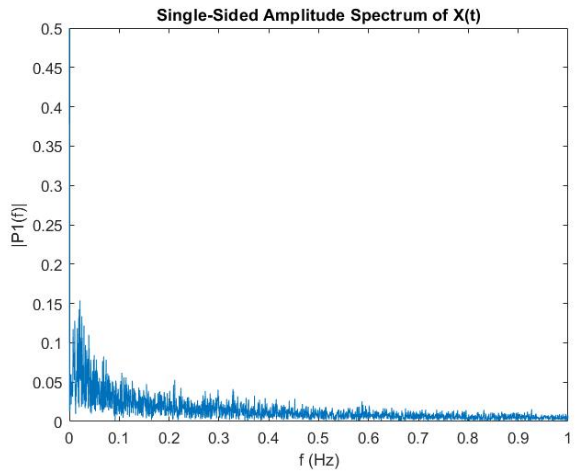

Figure 5.5: power spectrum of fore and aft acceleration

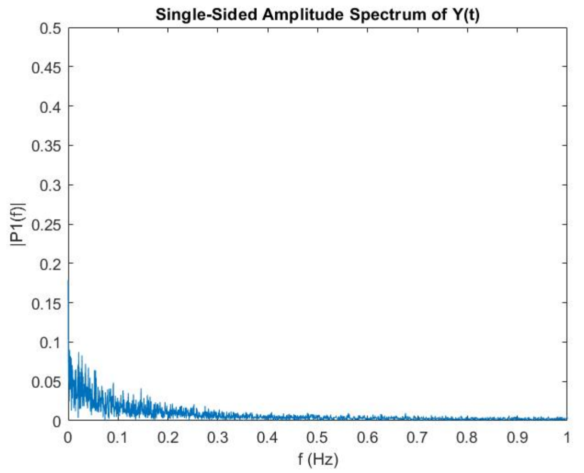

Figure 5.6: power spectrum of lateral acceleration

The power spectrum analysis of the accelerations reveals a lot more about the car motion. Lawther A.'s studies at sea showed that oscillatory vertical motions at 0.5hz and lower can cause motion sickness. Golding et al. [1997] studied lateral oscillations, specifically fore-aft oscillations and found similar results, with oscillatory frequencies below 1 Hz being sickening. Donohew and Griffin [2004] found significant effect of such oscillations for fore-aft as well as lateral oscillations below 0.2Hz causing motion sickness. On looking at the power spectrum of our acceleration data for x and y acceleration, we find maximal power below 0.2 Hz frequency, which, according to the cited literature, should be sickening.

However, to have better control over nausea levels during the study, it would be helpful to predict the expected nausea levels for our acceleration data. This is to ensure that the motion is not too sickening such that participants can't endure the entire duration of the study. The International Standard Organization (ISO 2631, 1997) and the British Standard Organization (BS 6841, 1987) use the VI model for predicting motion sickness incidence (percentage of people vomiting). A "motion sickness dosage value" has been defined to predict the percentage of people likely to vomit after exposure to a known motion stimuli.

$$MSDV = \sqrt{\int_0^T a_w^2(t)dt} \tag{5.1}$$

In the above equation T is the total exposure duration and a_w is the frequency weighted acceleration.
Using the MSDV and following Turner and Griffin [1999]'s regression model based on the plot 5.7, the predicted nausea percentage in people is approximated by the equations 5.2 and 5.3.

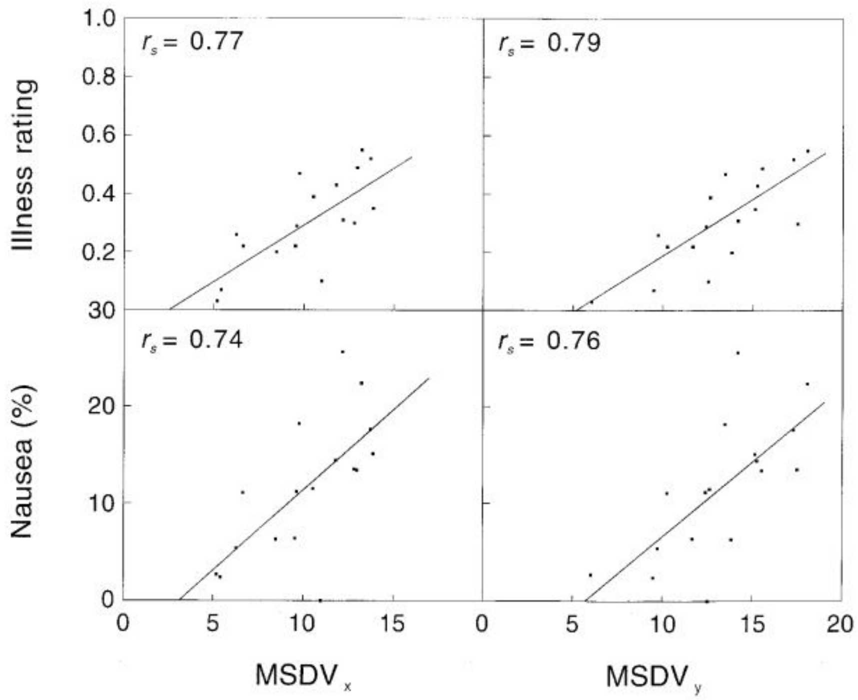

Figure 5.7: Graph relating MSDV to nausea in two axes based on the study by Turner and Griffin [1999]

$$\%nausea_x = 1.67 * MSDV_x - 5.42 \tag{5.2}$$

$$\%nausea_y = 1.53 * MSDV_y - 8.79 \tag{5.3}$$

The ideal simulator for sickness studies should be able to reproduce an actual car's accelerations well, especially the low frequency content (below 1 Hz) whilst maintaining a high enough amplitude so as to provide an adequate amount of Motion Sickness Dosage (MSDV) to the participants. Thus, our next aim would be to see how well the simulator reproduces this motion.

5.2.1 Simulator Tuning

For our purpose we look into reproducing the motions via the translation channel only. This is because tilting of the platform, though may recreate the perception of low frequency acceleration, does not provide the same motion sickness stimulus as true inertial acceleration. The absence of the tilt channel also greatly simplifies motion reproduction. The cueing algorithm is therefore tuned to preserve the low frequency content of the signal which comprises the most sickening frequencies, to this end, we use sine waves between 0-0.8 Hz .
The tuning involved the reduction of the high pass filter's cut off frequency to 2 rad/s (0.31 Hz) whilst keeping the input gain at 0.9 to reproduce the low frequency components with a moderate amplitude without pushing the simulator beyond it's workspace limits. We therefore arrive at the following tuning parameters.

Filter Omega = 2rad/s
Limiter gain = 0.9

The amplitude response of the simulator to the sickening sine waves is shown below in figure 5.8 for the above tunings.

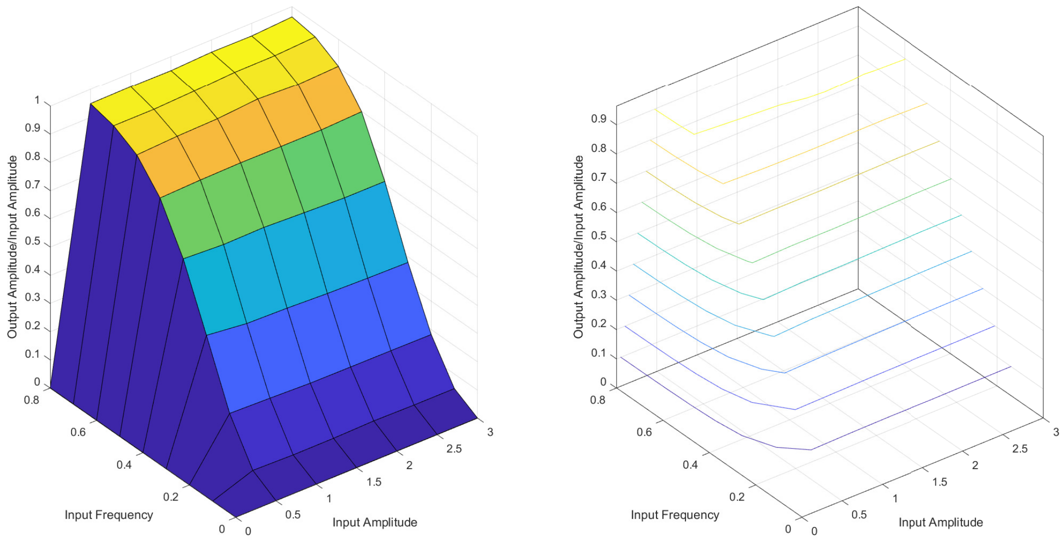

Figure 5.8: Normalized Amplitude response of simulator for final tuning

Now that the tuning is set specifically to reproduce the sickening frequencies well enough, we move on to the simulations.

5.2.2 Simulations

We first run the Hague drive's fore and aft acceleration data through our MSDV calculator based on equation 5.1 to obtain an MSDV value of 27.6, and consequently, a high nausea percentage based on equation **??** of 40.67 percent. Thus, the actual acceleration data collected is indeed highly sickening.
After running through the emulator with the tuning done, the simulator acceleration was fed into the MSDV calculator giving a lower MSDV value of 3.38, and subsequently, a nausea percentage of 0.22 percent which is too low for carrying out motion sickness studies with a practical number of participants, for instance out of 20 participants we can only expect 0.04 to become sick. To confirm, we can see the high levels of attenuation in the spectral analysis of the simulator acceleration, with barely any power in the sickening frequency range (see Figure 5.9).

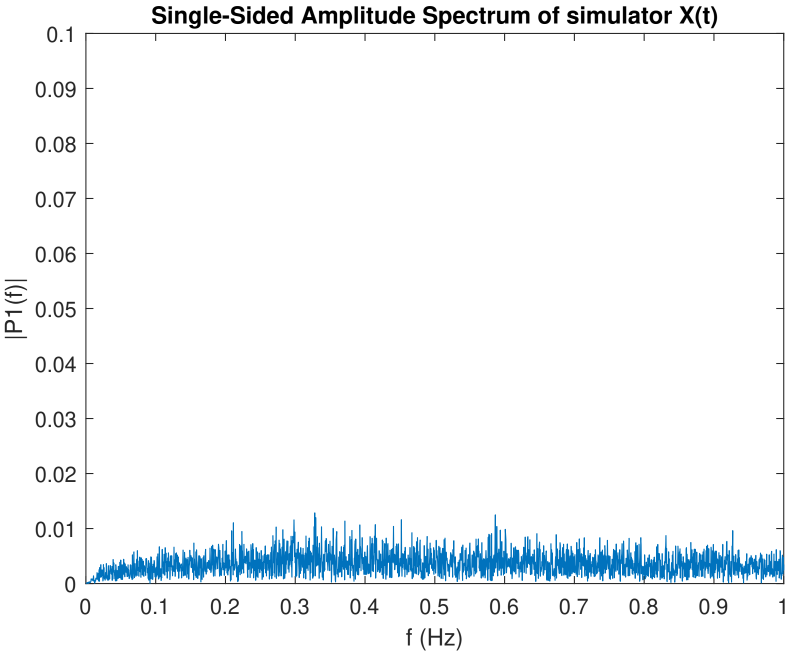

Figure 5.9: Frequency domain analysis of the hexapod's fore-and-aft acceleration based on the Hague acceleration data

Thus, the attenuation of a highly sickening motion profile of an actual car's motion is too much. We arrive at the conclusion that the simulator cannot reproduce an actual car's motion profile with the translational channel alone, and hence, the actual car data collected is not suitable for this study.

5.2.3 Sickening stimulus design

We then designed a more sickening stimulus for fore-aft and lateral motion using a multisine signal that the simulator can reproduce well whilst keeping the motion random from a participant's perspective. The power is spread across the sickening range of 0-1 Hz. Studies show that reducing predictability of the stimuli increases the end level of sickness [Kuiper et al., 2020]. Knowing the sickening frequencies, the multisine signal used consists of four sine waves with the respective amplitude and frequencies shown below
For the fore-and aft acceleration, the multisine includes the following sines: -
1) A = 2.0, f = 0.18Hz

2) A = 1.5, f = 0.35Hz

3) A = 1.5, f = 0.47Hz

4) A = 0.5, f = 0.80Hz

For the Lateral acceleration, the multisine includes the following sines: -
1) A = 1, f = 0.25Hz

2) A = 0.8, f = 0.4Hz

3) A = 0.8, f = 0.5Hz

4) A = 0.25, f = 0.75Hz

We now run a 1 hour version of this signal through the actual hexapod and analyze the hexapod acceleration data based on the sensors mounted on the hexapod. First, we look at the power spectrum of the simulator motion to see check the power distribution.

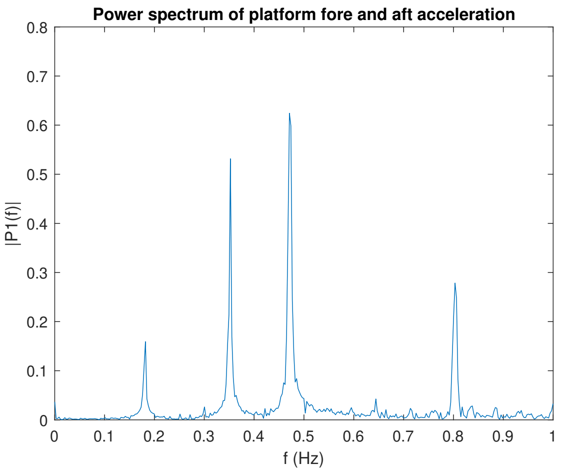

Figure 5.10: power spectrum of fore and aft acceleration of hexapod

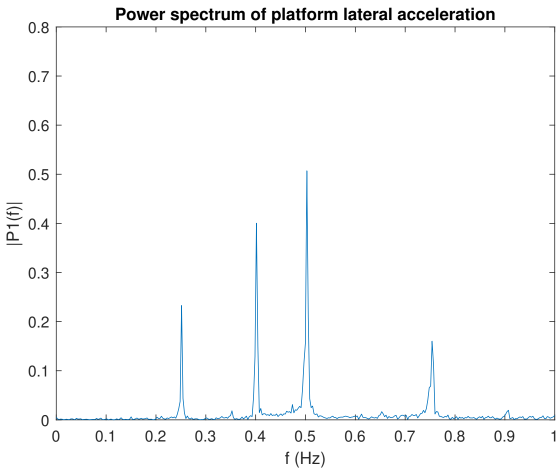

Figure 5.11: power spectrum of lateral acceleration of hexapod

The hexapod indeed reproduces the MultiSine a lot better than the actual Hague acceleration data, as seen in the frequency response, with the power at the required frequencies. To now check whether this motion is suitable for our study, we run the hexapod acceleration through our MSDV calculator, and the results as shown in 7.1 and 7.2.

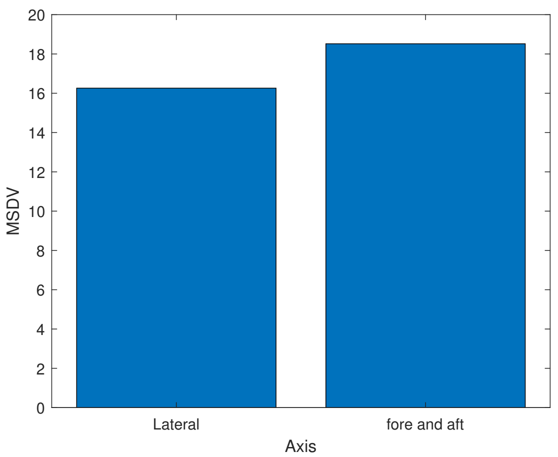

Figure 5.12: MSDV of hexapod acceleration

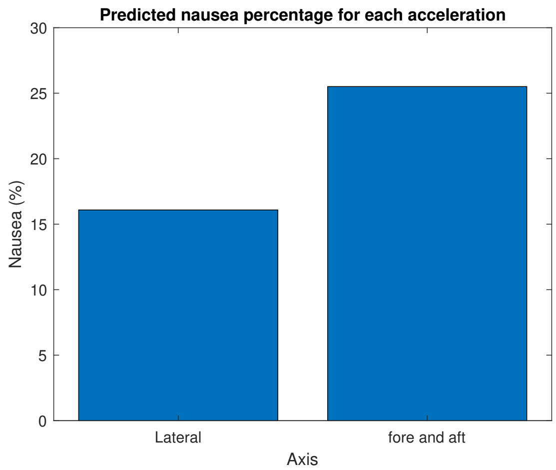

Figure 5.13: percentage nausea of hexapod acceleration

Looking at them separately, the predicted nausea for lateral and fore and aft axis comes to 16.09 percent and 25.51 percent respectively which is a moderately high level of nausea. The interaction of motion across two axes in terms of eliciting motion sickness is not well documented, and we use a vector sum to predict total nausea percentage which comes to 30.16 percent. This is adequate enough for our study and the motion profile design is finalized. Fine tuning of the motion intensity is done during the pilot for a more accurate experiment design.

Chapter 6

Cognitive Task

The task chosen to test cognition of humans is reading comprehension, as discussed earlier. To that end, we look at the ways reading comprehension has been tested.
Quite a few competitive exams test and quantify reading comprehension performances, such as TOEFL, IELTS, GRE, UCAT etc. All of these tests are standardized, and more importantly, tests used all over the world by students irrespective of their nationality or first language, with the same test duration and scoring criteria.
For example, John et al. [2009] used GRE reading comprehension tasks to study the performance of participants in a simulated office task. In his study, performance was measured as a percentage of questions answered correctly, which is a simple measure.

We shortlisted IELTS and UCAT as potential tasks to be used for this study. The paragraphs and related questions require participants to fully understand and integrate the given information, and discourage higher level classifications to 'guess' their way through. While the UCAT questions are all MCQs, IELTS academic reading task includes fill in the blank type questions and Picture labelling along with MCQs. To get baseline references, these tests were administered to 4 participants to decide which of the two would be more appropriate for the study.

For UCAT, each text has 4 questions. To go through four unrelated texts and answer 16 questions, we obtained an average score of 10.15 out of 16, with an average time of 21.2 minutes spent to answer all 16 questions. 3 out of the 4 participants found this test to be more engaging than IELTS due to all questions being MCQs and the questions being presented side by side with the paragraphs which allowed for a more efficient reading method, combined with shorter paragraphs.
For IELTS, each text is significantly longer than each UCAT text, and has 13 questions. The average score obtained is 10 out of 13, with an average time of 14.62 minutes spent to read each text and answer the related questions. 1 out of 4 participant found this text to be more engaging than UCAT due to the picture labelling question.

In the motion with motivation group, participants might take longer to answer IELTS questions due to the presence of fill in the blank type questions and labelling questions where they need to get the exact words right, in order to answer them correctly. For this, the scoring function designed will have to include time as a parameter with higher weights for each question. The UCAT thus has an advantage over IELTS due to its consistent questions in the form of MCQs, where if the participants have understood the text well, wouldn't take a significantly longer time in the motion-motivation condition. Of course, in the motion condition, participants are expected to take longer to read and comprehend the text. However, they won't have to spend a lot more extra time in trying to answer the questions. This helps in reducing the weightage that needs to be given to the time parameter in the scoring function, and perhaps, eliminate it completely.
Thus, we choose UCAT reading comprehension task in this study. The study is expected to last for around 60 minutes and hence we hope the participant can answer up to of 60 MCQs, thereby comprehending up to 15 reading texts, giving us a lot of data points to measure task performance.

Given that each participant has 4 experiment sessions, we need to have enough unique texts for participants to comprehend and answer questions to. Thus, the cognitive task is set up keeping the following points in mind: -

1) Participants should be given unique texts to perform the task on for each of the session, with no repeating questions.
2) The task difficulty must be controlled across the 4 experiment sessions to avoid confounds.
3) Each session should offer participants up to 60 MCQs or 15 paragraphs.
4) Data collection for the cognitive task should be convenient for both the participant and for the researcher.

For the online collection of this data, we use the software PsyToolkit [Stoet, 2010] [Stoet, 2017], which collects the time taken to answer each question as well as the answer accuracy in a clear format. The data can be used directly in either matlab or R for statistical analysis. 4 test sets were then created in PsyToolkit for the 4 sessions, with subjectively controlled difficulty levels. Each test set had 15 paragraphs (60 questions) which would be presented to the participant randomly, to control the test difficulty more. The 4 test sets were also randomized within the limitations of a Latin square scheduling to further control the difficulty level. The data collected is stored on the PsyToolKit database in an anonymized format as per the data protection laws, from which it is downloaded for analysis. The paragraph font, size and presentation are controlled across each test set. An example is shown in figure 6.1.

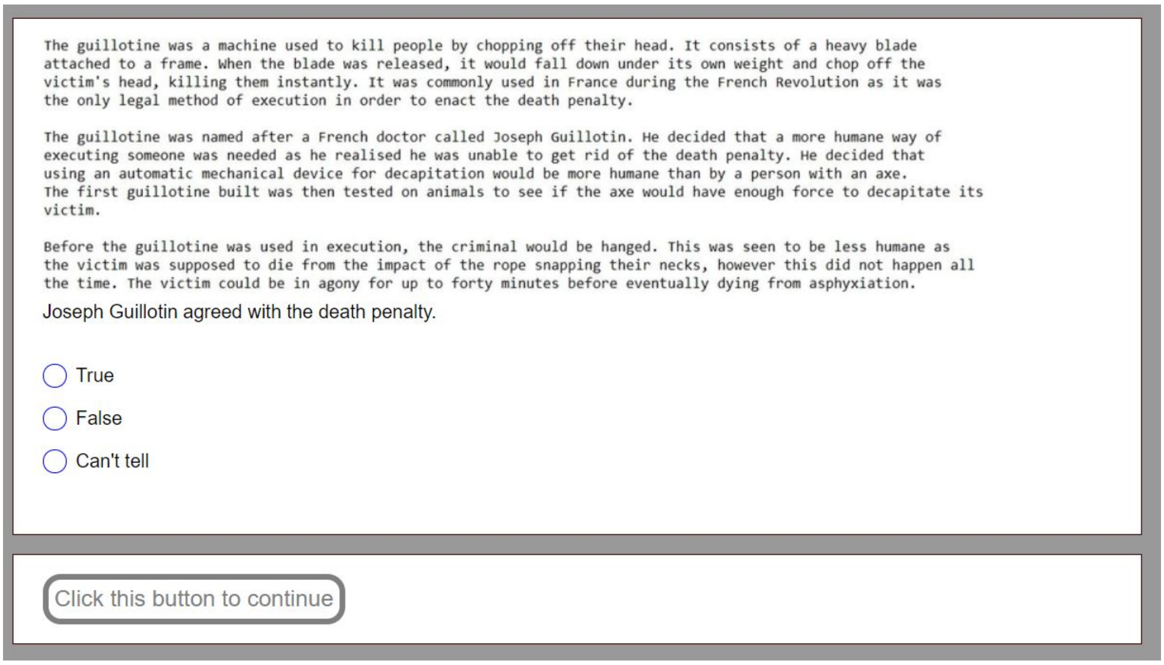

Figure 6.1: Example of Question presentation to the participant

The task duration is capped at 60 minutes, or until the participant completes all 60 questions. The participant may of course quit the experiment session at any point. For the task performance, we look at the following measures: -
1) Total score: Number of correctly answered questions.
2) Total time: Total time spent doing the task.
3) Time per question: Average time spent per question, which can give us further insight into the cognitive performance with time.

Chapter 7

Subjective measures

We now need to collect data on the individual participant perception of the variables that we want are testing, namely, motion sickness, motivation and workload to test our hypothesis and observe how our participants actually respond to our experiment design.

7.1 Measuring Motion Sickness

For the current study which involves rapid answering of questions, we would like participants to spend minimal cognitive effort in analysing their subjective motion sickness. The ideal questionnaire for collecting subjective sickness scores would be the Fast motion sickness questionnaire (FMS) [Keshavarz B, 2011] since we would like to collect sickness data online with a verbal scale, to minimize interference with the tasks at hand. The misery scale (MISC) developed at the TNO is another viable option for collecting this data online and quickly. The MISC scale takes only a few seconds to answer with a single numerical scale and can be administered every minute in the study.
We also need to analyse the general susceptibility of participants to motion sickness at the start of the study. The motion sickness history questionnaire (MSHQ) [Reason and Brand, 1975] collects data about past experiences with motion sickness and gives us a measure of the susceptibility to motion sickness of participants and is appropriate for this study.
For further insight into the participants sickness symptoms, it would be ideal to administer the MSAQ [Gianaros et al., 2001] at the end of the study .
MISC and MSAQ data would be interesting to study and could possibly show that motivation also reduces the subjective motion sickness, that is, motivation also mitigates the subjective sickness symptoms. Thus, we finalize the MSHQ to collect sickness susceptibility, MISC to collect online sickness data with time and the MSAQ to get a comprehensive look into sickness symptoms every experiment session. The MISC scale is integrated into the Cognitive task on Psytoolkit[Stoet, 2010] [Stoet, 2017], where it is presented once every two questions.

TABLE II. MISERY SCALE (MISC).

Symptom		score
No problems		0
Uneasiness (no typical symptoms)		1
Dizziness, warmth, headache, stomach awareness, sweating, . . .	vague	2
	slight	3
	fairly	4
	severe	5
Nausea	slight	6
	fairly	7
	severe	8
	(near) retching	9
Vomiting		10

Figure 7.1: the MISC scale

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.

Figure 7.2: Motion sickness assessment questionnaire

7.2 Motivation Questionnaire

Apart from factoring motivation into the experimental design, it would be ideal to collect subjective data on motivation to get further insight.
The Intrinsic Motivation Inventory (IMI) [Deci, Edward L. and Ryan, 2010] is a popular measure of motivation in literature. It is a multidimensional questionnaire which probes into the subjective experience of participants to tasks done in an experimental setting. Six subscales exist including interest/enjoyment, perceived competence, effort, value/usefulness, experienced pressure/tension and perceived choice when performing the task at hand. The subscale of interest/enjoyment is the main subscale that actually gives a measure of intrinsic motivation, even though the whole questionnaire is labelled as IMI. Rarely have all the subscales been used in an experiment. Experimenters usually have chosen specific subscales suiting their experimental setting. The primary issue with the IMI would be that the score is more inclined towards intrinsic motivation, whereas our study uses a purely extrinsic motivation.
Further research into existing literature on extrinsic motivation reveals the Situational Motivation Scale developed by Guay et al. [2000]. Situational motivation is based on the concept of the here and now of motivation [Vallerand, 1997] and refers to how motivated people are when they are engaging in the associated activity. Guay et al. [2000] found only one existing scale that measures both intrinsic as well as extrinsic motivation at a situational level by Conti et al. [1995]. However, the subscales within this scale have poor internal consistencies and have not been validated well. The authors themselves stated: "Because of the limited reliability of several of these scales, results of analyses on these variables must be interpreted with caution" (p. 1112)." Guay et al. [2000] concluded that no traditional scale exists that measures extrinsic motivation, and went on to construct and experimentally validate a new scale that measures intrinsic motivation, extrinsic motivation as well as amotivation called the Situational Motivation Scale, which is chosen for our experiment. The scale is slightly modified by the addition of 4 more questions (questions 17, 18, 19 and 20) that are relevant to our specific experimental design.

Why are you currently engaged in this activity?

1. Because I think that this activity is interesting	1	2	3	4	5	6	7
2. Because I am doing it for my own good	1	2	3	4	5	6	7
3. Because I am supposed to do it	1	2	3	4	5	6	7
4. There may be good reasons to do this activity, but personally I don't see any	1	2	3	4	5	6	7
5. Because I think that this activity is pleasant	1	2	3	4	5	6	7
6. Because I think that this activity is good for me	1	2	3	4	5	6	7
7. Because it is something that I have to do	1	2	3	4	5	6	7
8. I do this activity but I am not sure if it is worth it	1	2	3	4	5	6	7
9. Because this activity is fun	1	2	3	4	5	6	7
10. By personal decision	1	2	3	4	5	6	7
11. Because I don't have any choice	1	2	3	4	5	6	7
12. I don't know; I don't see what this activity brings me	1	2	3	4	5	6	7
13. Because I feel good when doing this activity	1	2	3	4	5	6	7
14. Because I believe that this activity is important for me	1	2	3	4	5	6	7
15. Because I feel that I have to do it	1	2	3	4	5	6	7
16. I do this activity, but I am not sure it is a good thing to pursue it	1	2	3	4	5	6	7
17. Because I want to win	1	2	3	4	5	6	7
18. I do this activity but I don't care about outperforming other people	1	2	3	4	5	6	7
19. Because I want to see how well I can do	1	2	3	4	5	6	7
20. I don't know; I don't care about my performance	1	2	3	4	5	6	7

Intrinsic motivation items: 1,5,9,13

Identified regulation items: 1,6,10,14, 19

External regulation items: 3,7,11,15, 17

Amotivation items: 4,8,12,16, 18, 20

Figure 7.3: Modified SIMS[Guay et al., 2000] for our study

7.3 Workload Questionnaire

To study perceived workload, we can administer the NASA-TLX questionnaire (NASA, 1986) at the end of the experiment for all conditions. With this, we have listed all the data that will be collected for analysis.

Chapter 8

Final Design Considerations and Conclusion

One of the more crucial aspects of human subject experiments is an informed consent form. The purpose of such a form is to inform the participants about the nature of the study as well as the associated risks involved clearly such that they can make an informed decision of whether to participate or not on their own. Such forms are expected to be read and signed by participants prior to the start of the study. The study would also have to be approved by the ethics committee in TU Delft. The informed sheet and consent form was finalized and the HREC form was submitted to the TU Delft ethics board. The green light by the ethics board was received within a couple of weeks and the experiment design was finalized. Sick bags and fizzy drinks were set up to increase comfort of participants post experiment if need be.
Each experiment session is set to be for 90 minutes at most, and the session time stamp is shown below: -

1) 0 min: Participant arrives

2) 5 min: Experiment briefing

3) 10 min: Participant is seated in the simulator with the task ready to go

4) 70 min (at most): Simulator is brought to rest and participant disembarks.

5) 90 min (at most): Participant recovers if sick and fills up MSAQ, SIMS and NASA-TLX self measures.

With 4 experiment sessions and 4 test sets, the scheduling via a Latin square is finalized below. We assign participants to each order as they sign up for the study with the 4 conditions labelled: -

1) C1 - No Motion No Motivator
2) C2 - Motion no Motivator
3) C3 - No Motion with Motivator
4) C4 - Motion with Motivator

Table 8.1: Experiment scheduling

	Session 1	Session 2	Session 3	Session 4
Participant 1	C1 (Test set A)	C2 (Test set B)	C3 (Test set C)	C4 (Test set D)
Participant 2	C4 (Test set B)	C1 (Test set C)	C2 (Test set D)	C3 (Test set A)
Participant 3	C3 (Test set C)	C4 (Test set D)	C1 (Test set A)	C2 (Test set B)
Participant 4	C2 (Test set D)	C3 (Test set A)	C4 (Test set B)	C1 (Test set C)

A pilot study was conducted on 4 volunteers where the motion intensity and the flow of the experiment was tested upon. The major outcomes of the pilot was to fix the motion gain at 0.8 times the original signal to ensure an optimum level of sickness and to not push the simulator's actuators too hard. A couple of questions that skewed the difficulty of certain test sets were changed to further control the difficulty level across all the test sets. With this, the experiment was ready.

Part III

Experiment Phase and Data Analysis

Chapter 9

Experiment Phase

We started with the recruitment of participants. To that end, we designed a poster(fig 9.1 with the important information and shared it on the cognitive robotics page on Brightspace, in 4 different student housings across Delft and Hague, on the TU Delft journal platform TU Delta and across the campus in the 3me and aerospace department. We ensured that none of the participants were friends with any of the experimenters to avoid uncontrolled intrinsic motivation and subsequent potential confounds.

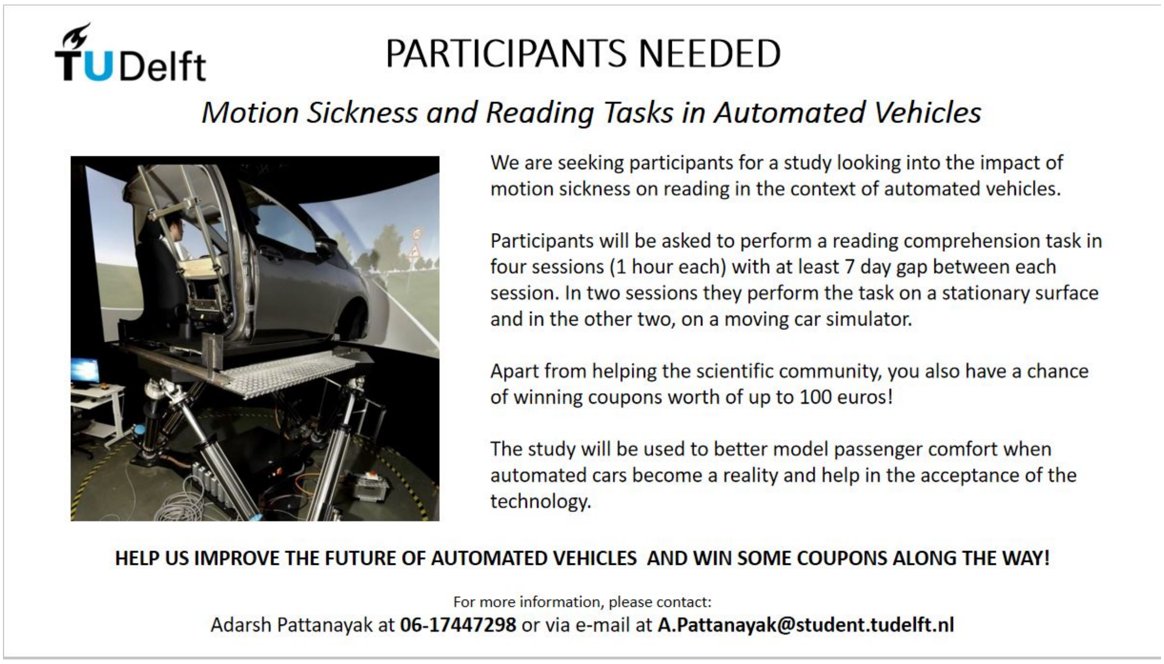

Figure 9.1: Poster designed

We got responses from 14 people who were interested to volunteer for this study, which was a lot lesser than the ideal number of participants of at least 24 participants which would give us a sample distribution which would be close to the population distribution (Hinton, 2004). The information sheet and the consent form was forwarded to them. After going through the forms, 9 volunteers confirmed their participation in the study. Each of the participants were assigned to a condition as given in table 10.1 and were assigned a number from 1-9 for anonymity.
On the first day of the experiment, participant 1, 4 and 9 were scheduled for their first session, which happened to be the motion condition. Out of the 3 participants, participant 1 was able to sustain the session for just 20 minutes while participant 4 and 9 could not endure the motion stimulus for more than 3 minutes, with participant 9 vomiting. This was really surprising since we had already reduced the intensity of the signal during the pilot to 0.8 times and our nausea predictor did not indicate a response such as this. We suspect that the interaction of the quasi-random fore-and aft acceleration and lateral acceleration towards the

feeling of motion sickness is a lot stronger than a simple vector sum of individual nausea predictions combined with the extremely high motion sickness susceptibility of the first three participants being the cause of such high sickness level. We would have to scale down the sickness intensity such that our participants would be able to endure 40 min to an hour of motion at moderate sickness while doing the cognitive task in order to get enough data points.
We conducted another short pilot session with some fellow researchers who are susceptible to sickness seated in the moving platform to gauge the motion stimulus strength at a gain of 0.8. Further fine tuning was done and we decided to reduce the motion profile's gain to 0.2 times the original strength. This was really surprising looking at our nausea predictor and is an interesting finding in the field of motion sickness at the interaction of motion along 2 different axes on sickness level. At 0.2 scaling factor, the predicted nausea according to our predictor came to 6.03 percent. The maximum platform acceleration in the x and y axes respectively were $0.51m/s^2$ and $0.37m/s^2$, which are, objectively, really low accelerations. Thus, we were able to elicit sickness with barely any load on the simulator actuators, which bodes well for future simulator-based sickness studies.
Since we had only 9 participants, we could not afford to lose the participants who had taken part in the initial session. We reached out to them and requested them to retake their motion condition. They were informed of the scaled down motion profile and of our intent to compensate them for their first session with a 10 euro coupon. Participant 1 and 4 agreed to retake the session at a later date while participant 9 backed out of the study, and with this, we had 8 participants and a fixed stimulus gain of 0.2 times the original strength.
The experiment phase continued smoothly after the first day. The motion conditions always took place on the motion platform while the no-motion conditions took place on the (stationary) motion platform or in the Toyota Prius, depending on the availability of the simulator.

Chapter 10

Data Analysis and Discussion

The 8 participants for the study (mean age = 26 years, STD = 2.87 years, 2 females 6 males) had a mean motion sickness susceptibility of 15.35 (STD = 13.72) based on the MSSQ indicating that they had above average susceptibility corresponding to the 63.7 percentile. The mean MSAQ scores of the motion condition (without motivation) was 34.63 (SD = 22.75). The standard deviation of MSAQ scores suggested a wide range of sickness susceptibility in our participants. The highest MISC value reached in our study was 10. For the motion conditions, all participants except participant 4, were able to complete the entire task. There was sufficient gap between the motion sessions to try and avoid habituation (mean = 18.75 days, SD = 6.13 days)

10.1 Testing task difficulty and analyzing sickness scores

Parikh et al. [2018] stated that answering a multiple choice question for a reading comprehension passage is done via option elimination and option selection by the human. They found that trained humans start with option elimination to eliminate options that are completely irrelevant to the text before moving to option selection, optimizing the time spent on the question. Thus, training effect, if any, would show up in the temporal performance of participants. Prepscholar, a GRE training service, mentioned that there are 3 approaches to reading comprehension: skimming the passage, reading the question first or reading the passage first closely and carefully (https://www.prepscholar.com/gre/blog/gre-reading-comprehension-tips/). The performance would depend heavily on the person's command of the language and the amount of experience with such tasks. With different strategies, training effects could be present. However, objectively evaluating the difficulty level of the 4 test sets would be very difficult with participant variability in skillset, with different participants potentially employing different strategies to tackle the same paragraph.
Since participant 4's task performance was heavily affected by motion such that he left both motion sessions pre-maturely, we do not consider his performance when looking for training effect in performing the task. Training effects, if any, are expected to help participants improve their temporal performance.

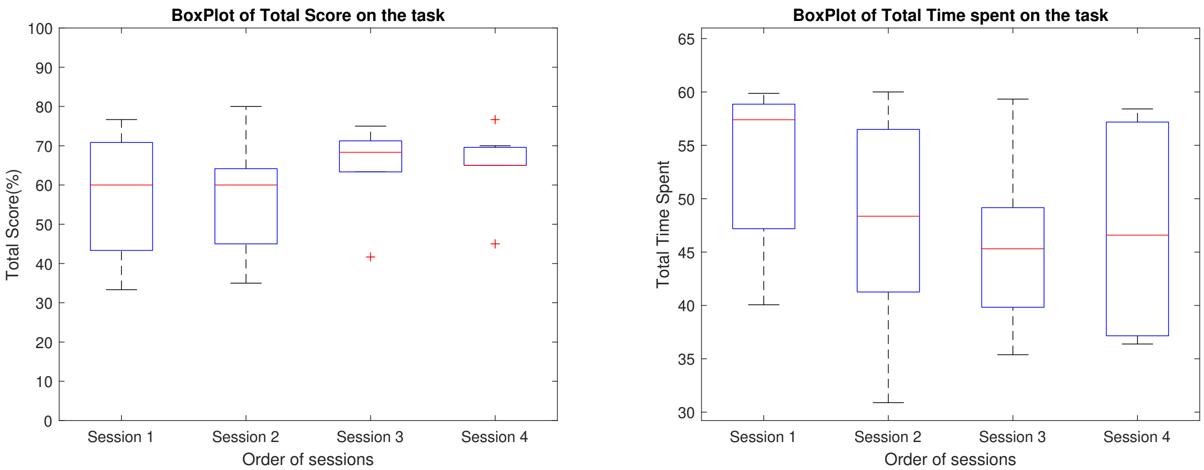

Figure 10.1: Task Performance in order of sessions

We use Friedman's test, which is suitable for a repeated measures study, to look for a training effect. We find a statistically significant training effect in the total time spent on the task (chi-square = 7.97, $p<0.05$), with participants requiring more time to perform the task in their first session (mean = 53 min, STD = 7.67 min) than the time required for their 2nd (mean = 47.73 min, STD = 10.23 min), 3rd (mean = 45.77 min, STD = 7.84 min) and 4th session (mean = 47.15 min, STD = 10.04 min), with counter-balancing of sessions incorporated. No significant difference in total scores is observed. This could have a confounding effect on the data.

Looking at the plot of the MISC values in fig 10.2 for the motion conditions and following the classification of sickness susceptibility of Matsangas and McCauley [2012], we found that all of our participants had sickness symptoms (at least to some extent) in the motion condition and are thus, symptomatic. We also observed a MISC level of 4 for participant 4 in the stationary condition. Being highly susceptible, the participant mentioned feeling uneasy and queasy in closed spaces, irrespective of whether motion is present. We observed some level of habituation to the motion in our participants when we looked at their MISC levels for the two motion conditions in the plots. Being a randomly balanced study, certain participants underwent the 'motion without motivation condition' first (P1, P3, P4, P7 and P8) while certain participants underwent the 'motion with motivation condition' first (P2, P5 and P6). We had a participant who was supposed to undergo the above condition first drop out of the study, as explained in the experiment phase section of this report, leading to a slight imbalance in the order. We observe that the MISC levels of participants 1, 2, 3, 5, 6 and 7 developed less rapidly for their second motion condition vis-a-vis their first motion condition. To test this statistically, we carried out Friedman's test on the MSAQ scores of the first and second motion session of participants. We found no statistically significant difference in the MSAQ scores in the two motion sessions (chi-square = 2.00, $p = 0.15$). Thus, even though the sickness symptoms might have developed slightly quicker in the first session, there was no real habituation to motion in our participants. The participants mentioned that they knew what to expect for their second motion condition and had become familiar with the simulator setting and felt more comfortable the second time around, which could explain the slightly slower rate of growth of sickness symptoms in the second session.

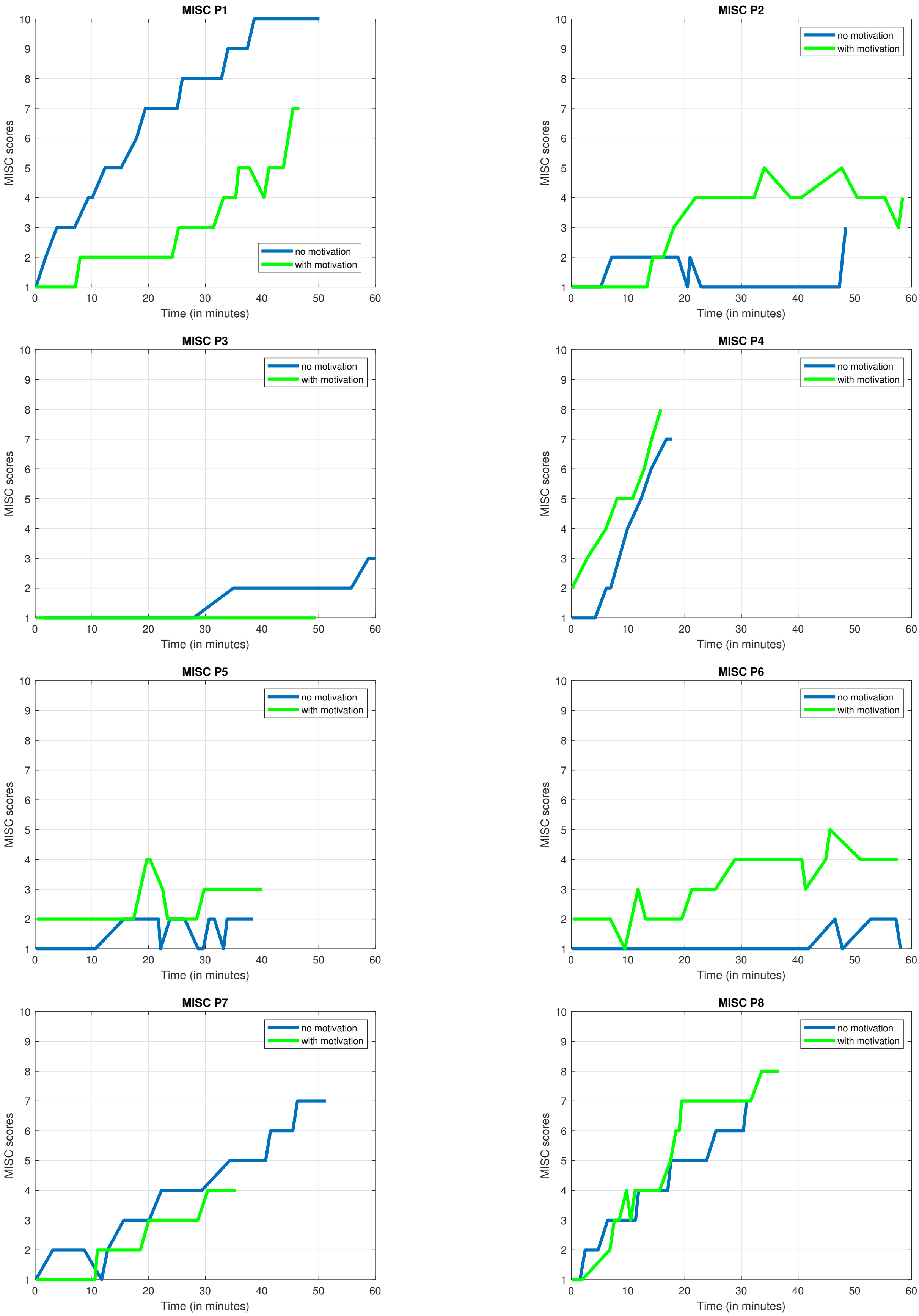

Figure 10.2: MISC values of each participant for the motion conditions

10.2 Testing our Hypotheses

We have stated our set of hypotheses to be tested below: -
1) Incentive improves task performance
2) Incentive reduces perceived motion sickness level
3) Incentive reduces perceived workload
4) Incentive increases perceived motivation
5) Motion reduces task performance
6) Motion increases perceived motion sickness level
7) Motion increases the perceived workload
8) Motion reduces perceived motivation
9) Impact of motion on task performance is lesser in the presence of incentive
10) Impact of motion on perceived motion sickness level is lesser in the presence of incentive
11) Impact of motion on perceived workload is lesser in the presence of incentive
12) Impact of motion on perceived motivation is lesser in the presence of incentive

Being a repeated measures study, our pooled data across the 4 conditions were not independent and contained within participant correlations. Shan et al. [2020] carried out 5 types of statistical analysis for a repeated measures study, namely: Pearson correlation, Correlation of Subject means, Partial Correlation for subject effect, Partial Correlation for visit effect and a Mixed-Model approach, and found a mixed-model approach to best account for such repeated measure data. For this study, we thus performed our analysis using a mixed model approach.
In a linear mixed effect model approach, a simple linear regression model is extended to include fixed effects (the independent variables) as well as random effects (arising due to within participant correlations), thereby accounting for the dependency of data. In a general form, equation 10.1 shows the model. Here, the interaction and subsequent effect of independent variable 'motion' and 'incentive' on variable y, which are our dependent variables, is analyzed and the $(1|participantID)$ term assigns a random intercept for each participant to account for within participant variability. This general form was adapted and used for each of our analysis.

$$y = motion * incentive + (1|participantID) \tag{10.1}$$

We analyzed the impact of our independent variables on our dependent variables using the above model, with the results summarized in table 12.1 and supporting plots in 10.3. The only significant effect observed was the effect of motion on MSAQ ($F(1,28) = 10.125$, $p < 0.05$), where motion caused motion sickness in our participants.

Table 10.1: Variable means and standard deviation across the conditions

Condition\ Variable	No Motion No Incentive	No Motion With Incentive	Motion No Incentive	Motion with Incentive
Total Task Score (out of 60)	35.125 (STD = 6.33)	33.62 (STD = 8.74)	33.00 (STD = 13.37)	36.00 (STD = 13.72)
Total Task Time (in min)	50.28 (STD = 9.11)	51.17 (STD = 7.90)	44.38 (STD = 14.43)	42.77 (STD = 14.28)
Average Time/question (in min)	0.91 (STD = 0.33)	0.98 (STD = 0.38)	0.85 (STD = 0.28)	0.87 (STD = 0.34)
MSAQ scores	12.76 (STD = 3.12)	13.10 (STD = 3.15)	34.63 (STD = 22.75)	34.20 (STD = 25.68)
NASA-TLX Workload scores	52.95 (STD = 14.97)	53.62 (STD = 12.76)	60.24 (STD = 16.87)	53.50 (STD = 21.61)
Motivation scores	53.30 (STD = 8.49)	56.10 (STD = 10.68)	48.98 (STD = 11.49)	50.20 (STD = 14.73)
Amotivation scores	29.12 (STD = 12.52)	31.00 (STD = 15.11)	34.62 (STD = 16.14)	29.25 (STD = 12.39)

Table 10.2: Test for Hypotheses 1-12

Exp Variables	Incentive	Motion	Incentive*Motion
Total Task Score	$F(1,28) = 205$, $p = 0.653$	$F(1,28) = 0.412$, $p = 0.525$	$F(1,28) = 0.925$, $p = 0.344$
Total Task Time	$F(1,28) = 0.038$, $p = 0.846$	$F(1,28) = 1.678$, $p = 0.205$	$F(1,28) = 0.150$, $p = 0.701$
Average Time/question	$F(1,28) = 0.720$, $p = 0.403$	$F(1,28) = 0.753$, $p = 0.392$	$F(1,28) = 0.137$, $p = 0.713$
MSAQ scores	$F(1,28) = 0.002$, $p = 0.960$	$F(1,28) = 10.125$, $p = 0.003$	$F(1,28) = 0.006$, $p = 0.936$
NASA-TLX Workload scores	$F(1,28) = 0.015$, $p = 0.900$	$F(1,28) = 1.877$, $p = 0.181$	$F(1,28) = 0.970$, $p = 0.333$
Motivation scores	$F(1,28) = 0.955$, $p = 0.336$	$F(1,28) = 2.271$, $p = 0.143$	$F(1,28) = 0.152$, $p = 0.699$
Amotivation scores	$F(1,28) = 0.243$, $p = 0.625$	$F(1,28) = 2.098$, $p = 0.158$	$F(1,28) = 1.823$, $p = 0.187$

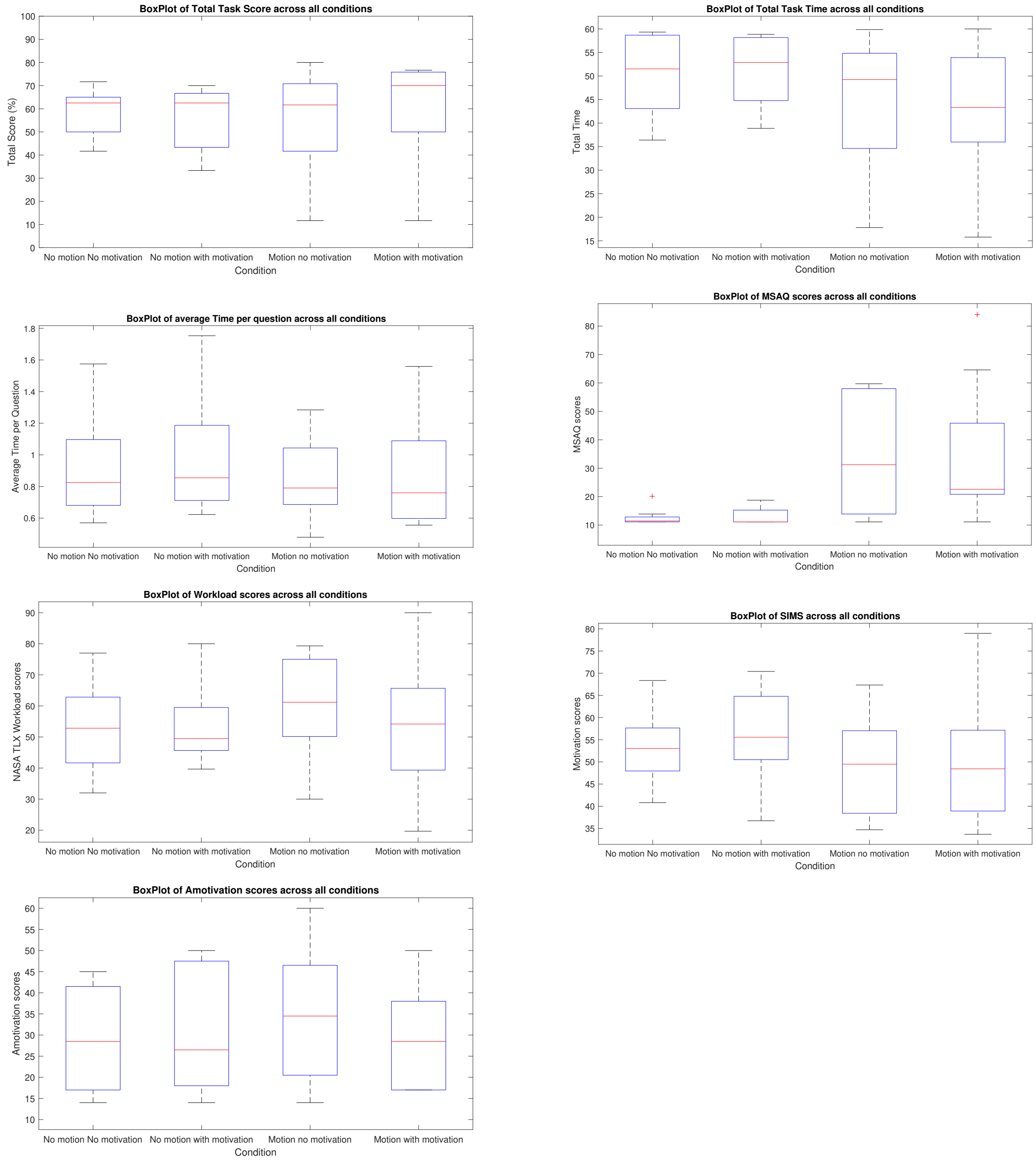

Figure 10.3: Dependent variable measures across all conditions

10.3 Secondary Analysis

With our research question, we were hoping to look at how the cognitive performance and workload of people are affected when they are motion sick and check whether, when motivated, motion sick people can still perform a cognitive task at a high level. Using our experimental design we could not prove our hypotheses. To further study this phenomena, we used linear mixed effects model to study the individual effect of the variables (without interaction effects, to check how each of our variables individually affected our dependent variables) that were better representations of what we tried to achieve with our experimental design, namely, the effect of MSAQ scores (measure of motion sickness) and amotivation scores as obtained from the SIMS questionnaire (measure of lack of motivation) on task performance and workload scores. The model is described in equation 10.2 where y refers to task performance and workload scores. This analysis will help in checking whether our experimental manipulation was of the right kind of variables.

$$y = MSAQ + Amotivation + (1|participantID) \tag{10.2}$$

Looking at the fixed effect of MSAQ scores and Amotivation scores on task scores, we found a non significant effect of MSAQ scores (F(1,29) = 0.90, p = 0.34) as well as amotivation scores (F(1,29) = 3.94, p = 0.056) on task performance. We see that the effect of amotivation score on task score almost reaches a significant value, and a larger sample size would give us a much better statistic. Amotivation score was correlated to task score with a coefficient of -0.26, implying that higher amotivation scores reduced task performance.
Looking at the fixed effect of MSAQ scores and amotivation scores on total time spent on the task, we found a significant effect of MSAQ scores on total time (F(1,29) = 11.91, p = 0.001) with a coefficient of -0.29 relating MSAQ score to total time spent. This implies that when sick, participants spend lesser time on the task suggesting a reduction in temporal performance (since they may need a longer time to complete the task). This can be attributed to the fact that susceptible participants cannot endure the motion long enough or lose the patience and motivation to complete the task and rush through it. However, our data could not show the latter trend of loss of motivation with increasing motion sickness. We found non significant effect of amotivation scores of total time spent (F(1,29 = 0.41, p = 0.52).
Looking at the fixed effect of MSAQ scores and amotivation scores on average time spent per question, we found no significant effect of MSAQ scores (F(1,29) = 0.86, p = 0.36) and amotivation scores (F(1,29) = 0.065, p = 0.79) on average time spent per question.

Looking at the fixed effect of MSAQ scores and amotivation scores on the perceived workload of our participants, we found a significant effect of MSAQ scores on workload scores (F(1,29) = 14.12, p = 0.0007) with a coefficient of 0.38 relating MSAQ scores to workload scores. This suggests that when asked to perform a task under motion sickness, people's subjective workload for the task increases vis-a-vis performing the same task in stationary condition. This is, in our knowledge, the first quantification of the effect of motion sickness on workload. No drop in performance was noticed in this study, probably because participants used more cognitive resources to tackle the task. However, in a naturalistic setting, people might just drop the task or perform it poorly depending on the level of sickness and the exact nature of the task. No significant effect of amotivation score was observed on perceived workload (F(1,29) = 0.82, p = 0.37).

Chapter 11

Conclusion and Future Work

Our initial analysis of the experiment showed that training effects were present in the performance. Participants adapted strategies to solve the cognitive task at a faster rate by the end of the first session, and this potentially interfered in the interaction of motion and incentive on task performance. For future studies, such tasks must have a trial session in place to avoid such training effects to confound the final data. We also found a trend of habituation in the participants to motion but it did not reached significant levels.
We could not conclusively prove our twelve hypotheses for this study using the current design and our participants. No clear difference in cognitive performance across the conditions was observed. Interaction of motion and motivation did not have any observable impact on any of our dependent variables. Analysis revealed that our motion stimulus design was definitely sickening and all our participants showed symptoms from very mild discomfort to high levels of nausea (owing to the wide range of sickness susceptibility between participants). This wide variance in sickness response also, perhaps, contributed to limiting the effectiveness of this study. Further, the two fold incentives of monetary reward and participant performance levels compared to other participants in the form of rank was, statistically, not a success. While interacting with the participants at the end of the study, we found that most participants did not care for their ranks vis-a vis other participants and very few participants, mainly bachelor students and international students were motivated by the monetary reward. However, the SIMS questionnaire does not reflect this. For example, looking at the SIMS scores for the two no motion conditions, we find only participant 2 who has a significantly higher SIMS for the motivation condition compared to the no-motivation condition. Similarly, looking at the two motion conditions, we find participant 3, 7 and 8 with a higher SIMS score for the motivation condition compared to the no-motivation condition. The first question that comes to mind is why were participants 3,7 and 8 not motivated during the no motion-motivation condition and why was participant 2 not motivated during the motion-motivation condition. Of course, this could be attributed to the participant's state of general motivation on that particular day of experiment. Another possible reason could be that despite instructing the participants of only the 2 motivation sessions being reward sessions, they attributed the incentive to the overall experiment. It could also be that the SIMS questionnaire was not understood properly by the participants. Few PhD participants and European master students said the monetary reward was rather insignificant for them and did not motivate them. Rather, they volunteered to participate to experience the experiment set up and the simulator study, and were thus, intrinsically motivated for the entire study. Thus, the incentive did not work very well for the study. This, coupled with the really small sample size, confounded the performance expected in the motivation sessions.

The secondary analysis revealed further trends in our data. We found a moderately negative impact of amotivation on the task score(which almost reached significant levels) obtained by participants. As the lack of motivation increased, participant performance dropped moderately in our study. Matsangas and McCauley [2012]'s research suggested that motion sickness reduces the motivation of people (or increases their amotivation) in general since certain symptomatic participants performed poorly in their task for their second session. In our study, we found how the lack of motivation (amotivation) affects task performance negatively, but could not link motion to increasing amotivation scores. It could be that motion causes motion sickness, which increases amotivation, thereby causing drop in performance, but our data could not statistically show this. As explained, in our study, perhaps the motion profile was not strong enough to drop enough motivation so as to negatively affect task performance. It could also be that our task was novel enough to help with motivating the participants intrinsically; however the SIMS questionnaire did not reflect this.
We found a moderate correlation between MSAQ scores and subjective workload, which shows that perform-

ing a task when motion sick increases the subjective workload of people. This has ramifications for tasks designed to be done by people when they undergo sickening motion. This increase in subjective workload, in our study, has a moderate impact on the total time spent by participants, with participants having to spend more time to keep their performance at a decent level. MSAQ scores also showed a negatively moderate impact on the total time spent on the task, implying that as participants got motion sick, they dropped out of the task or rushed through it, and ended the task earlier. This correlation analysis can perhaps explain why no clear drop in performance was observed in our study. As participants got motion sick, they took on the additional workload associated with it and spent more cognitive resources to keep their performance relatively high. The countering impact of the increased workload and the sickness levels on the total time spent resulted in no clear difference in the time spent across the 4 conditions as well.
Thus, a temporal decrement (longer time taken to solve the cognitive task) in performance was observed in this study when motion sick. This would have an impact in real world applications, where people working in automated cars would either rush through their work causing mistakes in task or just leave the task, rendering the possibility of getting work done in such situations moot, especially when the task requires sustained focus of the human.
Finally, the level of sickness in this study vis-a vis the motion dynamics was very interesting, from the point of view of conducting sickness related studies on a motion platform. Our original signal at full strength was expected to elicit a moderate level of sickness at 30.16 percent nausea after one hour of enduring the motion. However, the response from participants to the signal scaled down to 0.8 times the original intensity was unexpectedly high, with a couple of participants not lasting for more than 2 min. The signal was finally scaled down to 0.2 times the original signal, with a predicted nausea percentage of 6.03 percent, which is rather low. This elicited a moderate sickness response from participants. The maximum simulator accelerations along the x and y axes were really low at $0.5m/s^2$ and $0.37m/s^2$ yet they still managed to elicit a decent level of sickness in participants which shows real promise in conducting simulator based motion sickness studies. The interaction of random fore-and aft motion and lateral motion towards motion sickness is perhaps more complex than just a vector sum of predicted MSDV and sickness levels.

This study naturally gives rise to a lot of potential future work in this field of research. First and foremost would be to look into the interaction of random x and y accelerations on motion sickness, and finding a more accurate model to predict MSDV and nausea levels. This can be used to conduct a variety of comfort related studies on a motion platform while using the simulator workspace very efficiently.
Further research on motivation and it's impact on man-machine systems is a must. There is a lot of literature that shows how motivation affects cognitive performance. However, designing the motivation variable for a research study requires a lot of work. Our study used extrinsic reward based motivation which only worked for certain participants. We either only use participants who respond well to monetary incentives such as bachelor and international students or we need to work on a type of motivation that works well across a variety of participants. Further, if we follow a 2x2 within subject design, the motivation should be such that it is attributed only to the reward sessions. Perhaps a mixed subject design or a between subject design can work in this regard. However, using the motivation theory to carry out a robust test of a variety of motivation techniques and find the most consistent form of motivation can help in improving motivation based studies. Along with more research on the motivation variable, we also need a clearer and well verified method of subjectively measuring motivation. The SIMS is the only questionnaire that measures all aspects of motivation, rather than just intrinsic motivation. There is a lot of scope, thus, to develop and validate a more robust self measure of motivation that can be interpreted clearly by participants.
Apart from these, there are certain ways to make this particular study design more robust. First of all, the number of participants need to be a lot higher than what we were able to find due to the pandemic and the associated lockdown. Perhaps making this study a part of a bachelors course can help two fold- We can have a large sample size of bachelor students who also would be motivated by a monetary based extrinsic motivation. Our correlation analysis showed certain correlations that, with our limited and varied sample size, did not show differences across the conditions. However, with a larger group of students who would be motivated by monetary reward, we would definitely see clearer trends in performance across the 4 conditions. Having a larger group of participants can also help us group participants better using the severity of symptoms as the grouping variable (such as symptomatic, asymptomatic and neutral participants), resulting in lesser variance within group, as compared to grouping based on motion and no-motion. This confounding factor was also observed for the study done by Bos et al. [2005] Other options would be to change the study design completely from a within subject design to a mixed subject or a between subject design, so that participants don't attribute motivation to the overall experiment but to their specific conditions. Intrinsic motivation for this study might prove to be a more powerful motivator than extrinsic motivation. The only way we could think

of providing intrinsic motivation is by making the reading text more interesting and relevant to the participant. However, relevance of a reading text to a participant is highly subjective, and what might be interesting to one person may not be so for the other person, and this poses a difficulty in constructing the cognitive task.
We also received some constructive feedback from our participants at the end of the study. The most common feedback about the study design was the length of the study and the commitment participants had to make to the study, with no compensation whatsoever. 1.5 hours per session, with 4 sessions with at least a 7 day gap between each session perhaps is quite long, and some form of compensation might encourage more participants to volunteer. However, being a reward based study, a compensation would confound the motivation variable further. Participants mentioned that the difficulty level of the tests across the 4 conditions was consistent, and thus, UCAT as a cognitive task, worked well for this study, and can serve as a model for further cognitive studies.

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