Relationship of motion sickness with mental demand and cold sweating

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by

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Master Thesis

in

Human Technology Interaction

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Relationship of Motion Sickness with Mental Demand and Cold Sweating

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Abstract

Motion sickness occurs as a result of sensory conflict between the visual and the vestibular system. This is common to occur while reading or watching a video in a moving car and the degree of perceived motion sickness varies while performing these tasks. The aim of this study is three-fold. Firstly, this study tries to explore if the difference in perceived degree of motion sickness is related to a variation in mental demand. Secondly, this study explores if the degree of subjective motion sickness experience can be measured using three attributes related to cold sweating: skin conductance, skin temperature and relative humidity. Thirdly, a non-invasive seat mat is attached to the passenger seat used to measure the skin temperature and relative humidity because in a commercial car an electrode kit cannot be used to measure physiology to detect motion sickness. Therefore, this method of measurement is validated in this study.

To answer the research aims, a real driving study replicating the stop-and-go situation in daily traffic conditions is used to provoke motion sickness in 24 subjects. The motion sickness status and the physiological data is collected and analyzed. Skin conductance proves to be an excellent predictor of motion sickness. It has a strong positive relationship with motion sickness. Relative humidity around the back and upper thigh collected from the seat mat attached on the seat shows non-significant positive relationship with motion sickness. Skin temperature collected at the back and upper thigh measured from the seat mat attached on the passenger seat had a significant and positive relationship with motion sickness. Skin temperature measured using the finger had a negative and weak relationship with motion sickness. Thus, the non-invasive and invasive measurement techniques did not measure motion sickness at the same degree.

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This master thesis will always be a reminder of what I have learned throughout the two years that I spent at Eindhoven University of Technology and the eight months at Volkswagen. The things I learned in these two years are incalculable. Writing this thesis was not very easy for me, it took a lot of effort and I believe that there is still some more room for improvement.

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And I dedicate this work to my amazing parents, who are the best parents in the whole universe. Thank you Dharshu for being the best sister, my source of energy and inspiration. I am incomplete without you.

Harshini Sriram

2018

Contents

Chapter 1

This chapter introduces the topic of this master thesis and also contains a brief description of the research question and the importance of this research.

Introduction

Today, we live in a world with rapid advances in technology, especially in how we have been transporting from one place to another. The world has come a long way from using carriages and carts to today's superfast and self-driving cars. And throughout this advancement, there has always been one major problem which has been making transport unpleasant for most of us, that is, Motion sickness. Motion sickness is not just limited to cars, it is experienced in trains, ships, airplanes and also by astronauts in space. However, in this thesis the focus is on motion sickness that is experienced in cars. How big is this problem of motion sickness in a car? For a lot of people it is a very big problem. In a survey made by (Griffin, 1990) with 300 people 58% indicated that they experience motion sickness when traveling in a car, and 33% indicated that they vomited due to motion sickness.

With the advent of autonomous cars, the tasks in the car are completely redefined since the person doesn't have to drive anymore. And this gives the passengers space to perform secondary tasks like reading, watching movies or even preparing for a meeting. And this means that the potential to get motion sick only increases because motion sickness occurs due the underlying sensory conflict, where the information from the vestibular receptors (the ears) indicate movement, while the visual input is from the book or the phone. This sensory conflict in turn induces motion sickness and it occurs with signs such as sweating, pallor, drop in skin temperature and with symptoms like nausea, vomiting, stomach discomfort. Motion sickness can be detrimental and can negatively impact task performance by making the person feel nauseous or sometimes vomit restricting them from performing certain tasks while they are in the car. It is clear that motion sickness in cars is indeed a huge problem and as a first step the onset of motion sickness has to be detected to inform the passenger their well-being status. And later countermeasures can be developed to overcome motion sickness.

The aim of this study is three-fold, first aim is to investigate the relationship between perceived mental demand of the tasks and the motion sickness experienced. There has been very little information about the effect of mental demand on motion sickness from the previous research.

Moromito et al. (2014) reported that subjects experience severe motion sickness symptoms when they read than while watching a movie, however it was unclear what caused the difference in these two tasks. This study will therefore investigate the effect of mental demand on perceived motion sickness rating while performing tasks such as reading a book or watching a movie.

Secondly, the study focuses on measuring motion sickness using changes physiology of the subject. The physiological attributes are specifically related to cold sweating. Numerous studies have tried to detect motion sickness using both subjective (i.e., by means of questionnaires) and objective (i.e., by means of physiological changes) parameters. With respect to the latter, current research has focused on physiological measures like EDA and skin temperature that may be used to detect motion sickness. According to the previous research, EDA is said to increase with an increase in motion sickness. There is ambiguity in the results of skin temperature, while most studies report a negative relation between motion sickness and skin temperature (Bertin et al., 2005), some studies show an increase in skin temperature while a few studies report the opposite that skin temperature increases with motion sickness (Sjörs et al., 2014; Golding, 1992). This ambiguity may be a result of confounding factors such as, changing environmental temperature and relative humidity.

Relative humidity in this study has two uses, it is used to study if it confounds with skin temperature. It is also used to explore its relationship with motion sickness because with an increase in motion sickness there is an increase in sweat activity, therefore relative humidity around the body is expected to increase. This increase in relative humidity should also increase the skin temperature (Atmaca & Yigit, 2006). These relationships are explored in this study.

Thirdly, a sensor mat attached on the seat of the car is used to collect physiological data of the subject, is used as a non-invasive technique. This is compared with the classical method of data collection using electrodes, to determine if the data from the non-invasive technique is a reliable method of data collection. This non-invasive technique has to be validated because in order to detect motion sickness in commercial cars a classical electrode kit cannot be used by passengers for everyday use to detect motion sickness. However, the non-invasive seat mat used in this study only measures skin temperature and relative humidity from the upper back and thighs.

In this study an experiment was conducted to investigate if mental demand has an effect on the motion sickness experienced. Physiological attributes related to cold sweating such as, skin

temperature, EDA and relative humidity are tested if they can be used to measure motion sickness experienced.

Chapter 2 and 3 in this thesis contains all the necessary background information needed to understand this study. Chapter 2 describes the history of motion sickness, the theories that explain motion sickness, the relationship with mental demand. Chapter 3 describes how motion sickness was measured using subjectively and objectively using physiology in the past. Chapter 5 contains a description of the methodology used to conduct the experiment in this thesis. Chapter 6 contains a description of the results. Chapter 7 contains discussion of the results and recommendations for future work. Chapter 8 contains the conclusion of the study.

Chapter 2

This chapter provides information on motion sickness, which is required to understand this study.

2.1 Motion sickness – A short overview

Motion sickness: one must have heard this term sometime in their lifetime or at least a different variant of the term like travel sickness, car sickness, air sickness, sea sickness, simulator sickness, space sickness, etc. One thing about motion sickness is very clear from the name: it occurs due to movement. Perhaps motion sickness is not at all a new phenomenon, it was well known since the advent of transport but it was never well understood. The first ever recorded description of motion sickness dates back to 800 BC in the works of Homer (Huppert, Benson & Brandt, 2017). Back then traveling by sea was very popular and widely used for trade, but sailors often suffered from the "*plague at sea*" or sea sickness. In the ancient texts, sea sickness was indicated as the plague which caused people to vomit. Ancient Roman and Chinese literature on sea sickness also indicated symptoms related to the stomach and head, like vomiting and dizziness (Huppert, Benson & Brandt, 2017).

History also reports on motion sickness problems during time of wars, both on the sea and on the land. Soldiers got motion sick when they were mounted on camels and horses which led them to be ineffective during battles. During the World War II soldiers were motion sick and lost their fighting efficiency of fighting. This incident was reported as the "*greatest mass vomiting ever known in the history of mankind* " (Reason & Brand, 1975, p.18; Kennedy, Drexler & Kennedy, 2010).

These are but a few examples of the occurrence of motion sickness in the history of transportation. Recent encounters with motion sickness are encountered in modern transports systems like cars, busses, trains, airplanes. Motion sickness is also experienced in roller coasters and carnival rides which involve a head and body related movements that is similar to the what is experienced during space travel (Kennedy, Drexler & Kennedy, 2010; Kennedy & Graybiel, 1965). People also encounter motion sickness in virtual reality, simulator and video games that create the illusion of motion (Kennedy, Drexler & Kennedy, 2010). Motion sickness can occur due to visually induced movement is called *Visually Induced Motion Sickness*

(VIMS). VIMS occurs in the absence of a real physical movement but due to the perceived movement from displays, the only difference between traditional motion sickness and VIMS is the absence of real motion (Keshavarz et al., 2015).

The scope of this thesis is not on VIMS, but on motion sickness that occurs when there is absence of a visual stimulus indicating motion. For example, when someone is trying to read, or use a phone on a car, the brain receives movement information from the inner ear but being focused on the tablet or a book gives In the upcoming sections of this chapter we will uncover how motion sickness occurs.

2.2 How does motion sickness occur?

The term motion sickness has been used already in this report, it is very important to make clear that it is not an illness. Motion sickness, instead, is a physiological response that leads to developing symptoms such as nausea, sweating, fatigue, etc., and pathognomonic signs like vomiting or retching (Kennedy et al., 2010). Most people, when exposed to a provocative motion stimulus develop motion sickness reactions (Reason & Brand, 1975). The question now is, how does motion sickness occur? Theories state that almost every person with a normal vestibular function can be susceptible to motion sickness to varying degrees in the presence of a provocative stimulus (Lackner, 2014). Persons with complete loss of vestibular function are immune to motion sickness and those with unilateral loss are prone to lesser susceptibility than other people with properly functioning vestibular organs (Lackner, 2014; Reason and Brand, 1975). When a person gets motion sick it means that the vestibular organ is unable to translate motion signals into correct information to the sensory system (Kölndorfer, 2009). The upcoming section contains more information about the vestibular organ.

2.2.1 The Inner Ear

The vestibular system is located in the inner ear, and it is responsible for the detection of head motion and gravitational forces on the body. This system provides motion information to the vestibular centers in the brain which allows the body to retain a sense of balance and provides spatial orientation when there is detected motion (Khan & Chang, 2013).

The inner ear is a complex structure and it usually referred to in the literature as the labyrinth. It has two major sections, namely:

- Vestibular system (balance organ)
- Cochlea (hearing organ)

An elaborate structure of the labyrinth is shown in Figure 2.1, there are the three semicircular canals and the otolith organs (Utricle and Saccule) which make up the vestibular organs which provide head movement information to the cerebellum in the brain. The snail shaped Cochlea is the hearing organ.

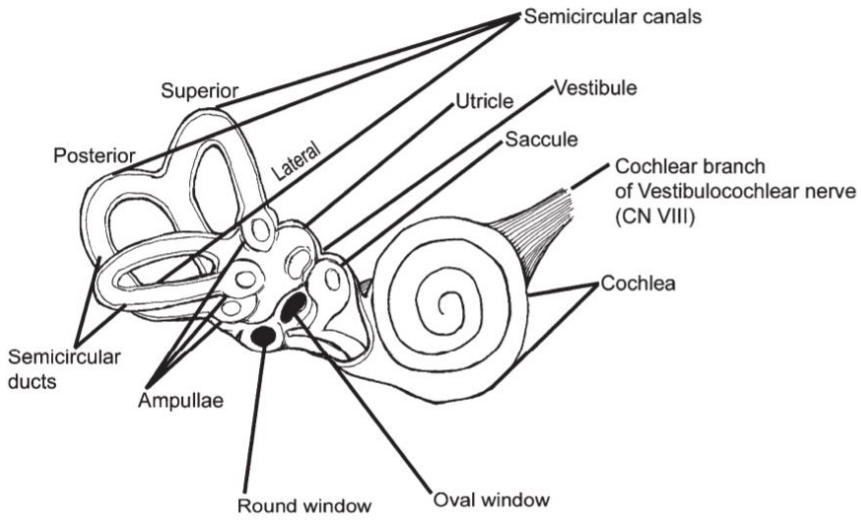

Figure 2.1 The inner ear : A detailed structure (Khan and Chang, 2013)

2.2.1.1 Function of the Semicircular Canals

The semicircular canals contain a space which consists of small hair cells and they are filled with a fluid. Since the inner ear is a part of the human head, it turns whenever a person turns the head leading to the movement of the fluid in the semicircular canals which simulates the movement of the hairs. This in turn sends specific movement information like nodding or rotating head to the cerebellum through the vestibular nerve (Sakamoto, & Hiraumi, 2014; Khan & Chang, 2013).

2.2.1.2 Function of the Otolith organs

The otolith organs, namely the saccule and the utricle also contain hair cells in them. The difference between the otolith organs and the semicircular canals is that the structure of the hair cells which are like small pebbles. The otolith organs provide acceleration information to the brain, such as forward/backward or upward/downward motion (Sakamoto & Hiraumi, 2014). They also provide the position information of the head in relation to gravity. Few examples of the acceleration information are when someone takes an elevator, or when there is sudden brake in a speeding car.

The vestibular organs send the motion and acceleration information to the brain and this information is passed onto to the other organs of the visual and proprioceptive systems (muscles and joints) to maintain body balance. With the help of the vestibular system, it is possible to know what position the body is in. Based on this information, the eye and muscle position can be adjusted to keep balance. This section has thus laid a foundation to understand the function of the vestibular organ, but why does the information from the vestibular organs causes motion sickness by causing dizziness or vomit is explained using motion sickness theories in the section below.

2.3 Motion sickness theories

The most common theories that explain the occurrence of motion sickness in the literature are (Golding, 2006; Warwick-Evans et al., 1998; Oman, 1990; Reason, 1978; Reason & Brand, 1975):

- Sensory Conflict theory
- Postural Instability theory
- Toxin detector theory

2.3.1 Sensory conflict theory

The sensory conflict theory is the most commonly referred to in motion sickness literature. One of the earliest incarnations of this theory was provided in the 17th century in the form of visual vertigo that occurs during sea sickness. Dizziness and nausea in sea travel occurs when the

spatial information through self-propelled movement is in conflict with the expectations of the motion senses due to the movement of the ship (Reason, 1978, p.820).

Reason and Brand (1975) postulated that the sensory conflict can exist in two forms, they are:

- Visual-Vestibular conflict
- Canal-Otolith conflict

In the visual vestibular conflict there is a mismatch between the Visual (A) and Vestibular (B) modalities. Whereas Canal (A) –Otolith (B) conflict is an intra modality conflict within the vestibular system itself. These two conflicts are further divided into three types, given that A and B represent normally correlated sensory systems, then the three types are:

- Type 1: Both A and B are simultaneously uncorrelated or contradictory
- Type 2a: When A is present but B is absent
- Type 2b: When B is present but A is absent.

Reason (1978), explained in his neural mismatch theory these types of sensory conflict with the help of everyday examples, which is depicted in table 2.1. However, Visual-Vestibular and Canal-Otolith conflicts can co-exist, the intensity of the canal-otolith conflict can be increased by a discrepant visual information. In summation, the information received from the visual system, the vestibular system, the proprioceptors and/or the gravitational information are in variance with each other which is explained to cause motion sickness.

	Category	
Type	Visual(A)-Vestibular(B)	Canal(A)-Otolith(B)
Type 1 (A and B together)	Looking from the side or rear window of a moving vehicle Watching waves over the side of a ship Making head movement while wearing an optical device that distorts the visual field	Exposure to cross-coupled accelerations Making rapid turning movements of the head in weightless flight
Type 2 (A in the absence of B)	Watching a Cinerama type motion picture shot from a moving vehicle	Caloric stimulation Positional alcoholic nystagmus and ingestion of deuterium oxide

	subjected to linear and or angular accelerations Riding in a 'haunted swing' fairground device Operating a fixed-base vehicle simulator with a dynamic visual display	Pressure vertigo due to ambient pressure changes
Type 3: (B in the absence of A)	Attempting to read a book or map in a moving vehicle Riding in an enclosed vehicle without external visual reference	Low frequency (less than 0.5 Hz) vertical oscillation Rotation about an earth-horizontal or off-vertical axis at constant angular velocity Counter Rotation

Table 2.1 Classification of different types of sensory mismatch as mentioned by Reason (1978) (p. 821)

The sensory conflict theory being the most widely accepted theory in literature, explains why motion sickness occurs. But it does not tell one about the how symptoms and signs occur. Therefore, there is a need of the toxin detector to explain why symptoms and signs occur.

2.3.3 Postural Instability theory

Stoffregen and Riccio (1991) postulated an alternative hypothesis to the sensory conflict theory. They state that motion sickness does not just occur due to the differences in inductive inferences an individual makes out of the world based on templates of the previous patterns and experiences. But they suggest that people become sick in situations for which they do not have an effective mechanism to maintain postural stability. "Motion sickness is characterized by situations of unfamiliarity in posture" (Stoffregen & Riccio, 1998, p.196). The crux of this theory is that postural instability is directly related to the magnitude of symptoms experienced, and postural control will reduce the severity of motion sickness (Warwick-Evans et al., 1998). They suggest that resting the head and lying down can reduce the effect of experienced motion sickness experienced by reducing head movements and allowing a stable posture.

Thomas et al. (2014) studied the head movements of the subjects during a game where they had to move an avatar around on a tablet. In one condition they had to move it using the touch screen and in the other condition they had to rotate the tablet. Their results indicated that the users who moved the tablet around also aligned their head according to the movement of the

tablet reported less motion sickness than the participants who did not rotate the head. These results support the postural instability theory of motion sickness.

Stott (1986) suggests a rule of thumb that the movement of the head should change in the direction the gravity vector. Also, there should be space stable visual input in case of head movements otherwise the vestibular information for the otolith (Golding, 2006). If this rule is disrupted motion sickness occurs.

2.3.3 Toxin detector theory

This theory suggests that the vestibular system has an additional function to act as a '*toxin detector'*. According to Triesman (1977), the brain has evolved to identify any mismatch in the expected pattern of visual, vestibular and proprioceptor information. This mismatch is identified by the brain as a malfunction in the central nervous system due to a possible in taken neurotoxin, and it elicits an immediate response to get the toxin out of the body. This theory states that motion sickness is nothing but a defense reflex which occurs due to sensory conflict (Reason & brand, 1975; Golding, 2006). The conflict in the visual, vestibular or proprioceptive system initiates few autonomic responses which disrupts the balance of the Autonomic Nervous System (ANS; Muth, 2006). When the balance of the ANS is disturbed by a motion sickness stimulus, symptoms and signs appear because due to the releasing of neurotransmitters. It follows a kind of a negative reinforcement response to conflicting sensory signals where the body removes the poison out through reactions such as vomiting. This explains why there might be possible symptoms that occur due to motion sickness.

In summary, all these theories are needed in order to explain the occurrence of motion sickness. This study tries to recreate the phenomenon of experiencing motion sickness in a regular stop and go traffic situation while reading a book or using the phone in a car. This phenomenon is based on the above mentioned theories which will be elaborated in chapter 5.

2.4 Motion sickness signs and symptoms

In this section, the symptoms of motion sickness are discussed. Motion sickness is frequently defined as a condition that is characterized by certain physical signs such as vomiting, pallor, sweating, etc.; symptoms such as nausea, fatigue, stomach discomfort etc., (Reason & Brand,

1975). The conflict in the visual, vestibular or proprioceptive system initiates few autonomic responses which disrupts the balance of the ANS which in turn lead to physiological responses.

The three most commonly reported symptoms are pallor, cold sweating and vomiting (Money, 1970) . However, nausea is the most frequently reported symptom. Dizziness, fatigue, headache are observed in a few studies (Maitland, 1931; Money, 1970).

Apart from these symptoms, motion sickness co-occurs with cardiovascular signs, such as: increased pulse rate, rise/fall of blood pressure (Doig, Wolf, & Wolff, 1953). Respiratory signs like increased ventilation, slow respiration, sighing and yawing are also reported (McEachern, Morton, & Lehman, 1942; Money, & Friedberg, 1964).

There are temperature signs which are observed like, fall of body temperature, skin temperature and mouth temperature and cold sweating is also experienced (McEachern, Morton, & Lehman, 1942). Difference in pupil size is also a sign of motion sickness, pupil size is said to decrease and dilate (McEachern, Morton & Lehman, 1942; Money, 1970). It is important to differentiate motion sickness signs and motion sickness symptoms. The symptoms are subjective evidence for the occurrence of motion sickness that can be felt by the person experiencing motion sickness. Signs are objective and can be detected by an external examiner or a motion sickness researcher. There are a few initial physiological events that occur which cannot be detected by just ocular examination. Sometimes even affected subjects do not feel the initial symptoms of motion sickness. For instance, pallor cannot be felt by the affected person but can be detected by an external examiner.

Motion sickness also takes a toll on mental well-being during motion sickness exposure, common symptoms are depression, anxiety, feeling of disinterest, mental confusion, sensitivity to odors (Money, 1970). Motion sickness also causes a declination in performance and behavior. Motion sickness is a huge problem which occurs with the signs and symptoms, however, the degree of these signs and symptoms experienced is not the same across all people.

2.5 Motion sickness Susceptibility

Does every individual with fully functioning visual and vestibular system experience the same amount of motion sickness? The answer is no. Susceptibility defines the degree at which an individual responds to motion sickness. Susceptibility to motion sickness differs from person

to person, individual differences in motion sickness susceptibility are very high. Only persons with complete loss of vestibular organs do not experience motion sickness, the rest of the population is susceptible to motion sickness at varying degrees. Golding (2006) states that there are three processes at work in relation to susceptibility to motion sickness: Initial sensitivity to motion, rate of natural adaptation, and the ability to retain the adaptation on a longer term (Golding, 2006, p. 69). Also, repeated exposure to the same kind of motion reduces susceptibility to motion sickness over time.

In addition there are a number of other factors which influence the magnitude of motion sickness experienced, they are:

- Patients with any medical conditions
- Persons with vestibular pathology (Golding, 2006)
- Genetic contribution (Finley et al., 2004)
- Gender, females are highly susceptible due to the change in hormonal cycles(Lawther and Griffin, 1988)
- Age: infants and children between age 0-7 are more susceptible to motion sickness than adults (Reason & Brand, 1975)

Money (1970) stated that there are numerous possible changes that occur in the ANS that can account to detection of motion sickness, however these changes are not consistent among all individuals. Parker, Schaffer, and Cohen (1972) in their study showed split their group into susceptible and non-susceptible subjects, where all the susceptible people either vomited or reported severe nausea when they were exposed to motion stimuli and the non-susceptible people did not report any symptoms. And Crampton (1955) showed that there was a greater increase in ANS signs like, decrease in gastric tone, increase in pulse rate, and respiration among the subjects who vomited.

Individual susceptibility was measured for decades using the Motion Sickness Susceptibility Questionnaire (MSSQ) by Reason and Brand (1975). However, Golding (1998) redesigned this questionnaire and came up with the MSSQ Short version. Golding redesigned the MSSQ because the original version was not very easy to fill without guidance and explanation by the researcher and there was high chance of errors.

The MSSQ short has two sections, which measures motion sickness in different modes of transport up to the age of 12 and the experience during the past 10 years and the total score is

calculated adding both the scores, figure 2.3 provides the percentile of people with different MSSQ scores. In summary, individual susceptibility to motion sickness varies and it can be reliably measured using the MSSQ based on this questionnaire it is possible to say if a person is more or less susceptible to motion sickness.

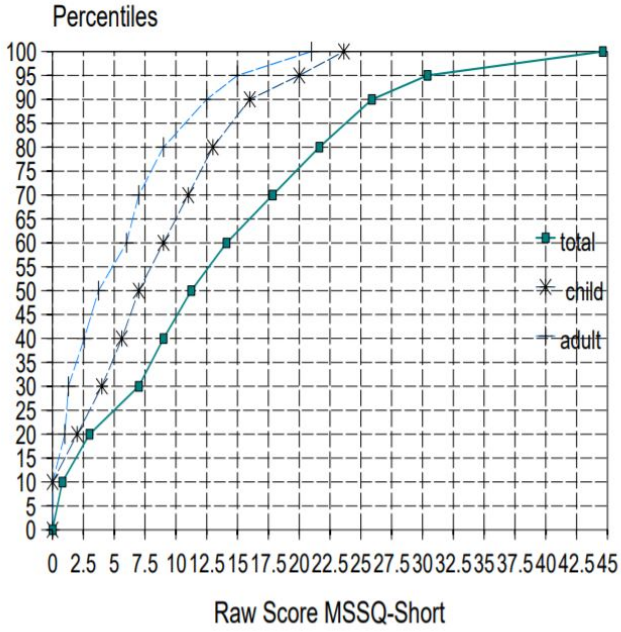

Figure 2.3 Raw MSSQ scores from 247 subjects plotted against percentiles, 50th percentile of total MSSQ short score is 12.

Chapter 3

The previous chapter provided an overview and the information required to understand the phenomenon of motion sickness. How does one tackle the problem of motion sickness? The first step is to detect the occurrence of motion sickness in a passenger. In cars this information can be used to inform the passenger about their well-being state so they can use this information to counteract motion sickness. Ultimately, the aim is to have a system in the car which would guide the passengers on how to counteract motion sickness. In this chapter an overview of motion sickness detection is provided.

3.1 Motion sickness detection

Lackner (2014) says that *much of motion sickness goes unrecognized*, because some symptoms of motion sickness can be interpreted as due to just fatigue or boredom, when in reality they are due to exposure to real or apparent motion. Nausea or vomiting are not the only symptoms of motion sickness, there are also other symptoms such as yawning or decrement of performance which might not be recognized by the person subjected to motion sickness. The onset of motion sickness in a controlled laboratory can be detected easily because the researchers usually clearly explain the subjects about the symptoms of motion sickness and they are also experienced to look for signs while they induce their subjects to motion stimuli that cause motion sickness.

In motion sickness studies, the onset of motion sickness is measured using two methods, separately or in combination with each other, they are:

- Subjective methods
- Objective methods

3.1.1 Subjective methods

In motion sickness studies the subjective method of motion sickness evaluation is used. Motion sickness is a phenomenon that is experienced by an individual, therefore it can be perceived and reported by the individual. In motion sickness studies, the motion sickness symptoms are

elucidated to the subjects, therefore they are aware that the symptoms they experience are due to motion sickness and consequently report them. An example of a typical motion sickness questionnaire used is reported in table 3.1 (Kennedy & Fowlkes, 1992).

Do you have any of the following symptoms right now? (tick boxes)				
	0	1	2	3
	None	Slight	Moderate	Severe
General discomfort				
Fatigue				
Headache				
Eye strain				
Difficulty focusing				
Increased salivation				
Sweating				
Nausea				
Difficulty concentrating				
Fullness of head				
Blurred vision				
Dizziness (eyes open)*				
Dizziness (eyes closed)*				
Vertigo				
Stomach awareness				
Burping				

Table 3.1 Motion sickness questionnaire developed by Kennedy and Fowlkes (1992).

The scale in table 3.1 requires a lot of effort from the subject and cannot be used in case of quick analysis of the symptoms. To measure the development of the level of motion sickness over time a rather simpler scale has to be used.

One such scale that is used is the Borg scale (Borg & Borg, 2001), this scale is a verbally leveled anchored scale which is a category rating scale. The scale ranges from 0-10 with labels and numbers to rate the level of motion sickness severity experienced (table 3.2). This scale is used to rate each symptom of motion sickness separately such as nausea, dizziness, and head ache. It can be an arduous task for the subject to differentiate each symptom experienced.

Absolute maximum	
10	Extremely strong
9	
8	

7	Very strong
6	
5	Strong
4	
3	Moderate
2	Weak
1	Very weak
0	Nothing at all

Table 3.2 Borg 10 rating scale

The more common scale used is by Golding (1992), it is a 7 point likert scale: 1- No symptoms, 2- Any symptoms however slight, 3- Mild symptoms, 4- Mild nausea, 5- Mild to moderate nausea, 6- Moderate nausea but can continue, 7- Moderate nausea and want to stop. The following scale was also used: 1- no symptoms; 2- initial symptoms of motion sickness but no nausea; 3- mild nausea; 4- moderate nausea; 5- severe nausea and/or retching; 6- vomiting (Golding et al., 2003). These scales have confusing labels and not every subject might experience nausea, for that purpose this study uses a reconstructed scale to measure motion sickness levels which is described in section 5.

The self-report questionnaires are generally used at regular intervals throughout the duration of the motion sickness stimulus exposure, to track the gradual development of motion sickness symptoms. The self-report questionnaires alone do not provide enough motion sickness information because a few signs and symptoms cannot be felt by the subject or they are not fully aware of the symptoms. Therefore they are usually used in combination is objective measurements which can be observed and measured by the experimenter.

3.1.2 Objective methods

There are numerous psychophysiological measures that can be measure motion sickness objectively (chapter 2.4). However the focus of this thesis will be on three measurements related to cold sweating, namely: Skin conductance, Skin temperature and Relative humidity.

3.1.2.1 Electro Dermal Activity (EDA)

EDA is measured as skin conductance and the unit is microsiemens (µS). The EDA is measured using two electrodes placed on an emotionally sensitive location of the body while applying a constant low voltage the resulting electrical current between the electrodes is reported as skin conductance (Bouscein, 2012) . Skin conductance is positively and strongly correlated with the activity of the sweat glands. It can be used to measure the activity of the sympathetic nervous system which provides information about the individual's arousal to stimulus that is provided (Bouscein, 2012). Skin conductance can be recorded at different location of the body, the fingers and the palmar surface are commonly used since the palmar region contains around five thousand sweat glands (Andreassi, 2000).

Cold sweating which is the concurrent perspiration and feeling of cold, is a very common motion sickness symptom, sweating increases as a person gets motion sick Crampton (1955). Crampton (1955) was one of the first to study the relationship between sweat and motion sickness, in his study it was identified subjects showed increased sweat activity when exposed to motion sickness provocation.

Previously, numerous studies investigated the relationship between EDA and motion sickness. EDA is often found to be a very good measure to detect motion sickness and a strong positive correlation between EDA and motion sickness is observed in these studies. EDA is measured as either tonic or phasic activity. Tonic activity is also called as Skin Conductance Level (SCL). SCL changes slowly over time, they can be between 2-100 microsiemens, SCL is the overall conductivity of the skin ranging between seconds to minutes. In contrast, Skin Conductance Responses (SCR) and are the phasic activity of the skin conductance. SCRs last a few seconds, they form steep peaks and then return to the baseline, they range anywhere from 0.2-20 microsiemens.

Golding (1992) wanted to study the relationship between motion sickness and skin conductance activity. The aim of his study was to compare the choice of tonic and phasic signal to analyze the severity of motion sickness at a low frequency motion. The results of the study indicated that SCRs correlated very strongly with motion sickness, while SCLs correlated comparatively weakly. While, Sjörs et al. (2014) studied the relationship between physiological responses and motion sickness, the results suggested a strong positive correlation between SCL and motion sickness. Similarly, Bertin et al. (2005) and Meusel (2014) also studied the relationship

between SCL and motion sickness, the results clearly indicate the great potential of SCLs to detect and measure motion sickness.

3.1.2.2 Skin temperature

Skin temperature is a measurement of temperature at the outer or the volar surface of the skin. It is measured by using a thermistor on the forehead, volar surfaces such as the palm or the bottom portion of the feet. The skin temperatures is reported in degree Celsius or Fahrenheit. Skin temperature is used to indicate mental strain. During sympathetic arousal the blood vessels are constricted which decreases skin temperature and increases blood pressure. Therefore, skin temperature is used to measure the activity of the ANS (Sjörs, 2010). Skin temperature is therefore said to decrease with an increase in motion sickness. Bertin et al (2005) reported a decrease in skin temperature with an increase in motion sickness. While Sjörs et al (2014) and Golding (1992) reported an increase in skin temperature with an increase in motion sickness. The results of skin temperature with respect to motion sickness is ambiguous.

To explain this ambiguity, Scott (1988) in his study on the effects of motion sickness on the human thermoregulatory mechanisms argues that the autonomous thermoregulatory system dysfunctions during motion sickness. In addition, environmental Temperature may confound skin temperature recording at the thermoregulatory skin sites (Golding, 1992). Skin temperature must be measured in a thermo-neutral environment between 23- 27°C. Ambient temperature below approximately 20°C may shut down thermoregulatory sweat glands and render them non-responsive to motion sickness, excessive temperature may trigger thermoregulatory sweat gland activity and therefore obscure any effects of motion sickness. Therefore, skin temperature has to be measured while keeping constant the environmental temperature at a thermo-neutral environment. Also, in the thermoregulatory mechanism relative humidity is often measured with an increase in relative humidity (Atmaca & Yigit, 2006), the skin temperature increases. Relative humidity in addition can be a confounding variable in motion sickness studies. Though, theoretically skin temperature is supposed to decrease with an increase in motion sickness, the results may be ambiguous due to confounding factors.

3.1.2.3 Relative humidity

Relative humidity is never used in motion sickness studies to objectively measure motion sickness. Relative humidity is strongly and positively related to skin temperature. Relative humidity is expressed in percentages (equation 3.1).

$$Relative\ humidiy(\%) = \frac{actual\ vapor\ density\left(\frac{g}{m^3}\right)}{saturation\ vapor\ density\left(\frac{g}{m^3}\right)} \times 100$$

Equation 3.1: Relative humidity

The thermoregulatory processes in the body occur to maintain a balance between the body temperature and the surrounding. In high humidity, the latent heat dissipation capacity of the body decreases depending on the increase in vapor pressure and as a result the sweat rate of the body increases (Atmaca & Yigit, 2006). Atmaca and Yigit (2006) also studied the relationship between relative humidity and skin temperature, they observed that the skin temperature always increased at higher humidity, this is the reason why people sweat and feel hotter in high humid environments. Therefore, relative humidity can be a confounding factor while measuring skin temperature. This study measures both the temperature and humidity from the body and also the environment.

Thus, this study tries to explore if any relationship can be established between relative humidity and motion sickness on the basis of its relationship with skin temperature. Thus an assumption about the relationship between relative humidity and motion sickness is made with the help of underlying theory. Sweating occurs during motion sickness, sweat vaporizes which can cause an increase in relative humidity around the body. This increase in relative humidity may be the cause of the increase in skin temperature as the body tries to keep a thermal balance. This relationship is explored in this thesis.

3.2 Motion sickness, performance and mental demand

Decline in performance and fatigue were reported as symptoms of motion sickness, discussed in section 2.4. A decline in performance due to motion sickness is undesirable, it disrupts working in a moving environment. For instance, an extremely susceptible person cannot work on their tablet or read a book while traveling in a car. Research has demonstrated that

performing tasks that included the use of short term memory declined performance faster when the individual was subjected to motion sickness (Levin et al., 2007; Paula et al., 2005).

These studies consistently showed the effect of motion sickness on performance during tasks. The accountability of the type of task performed to the experienced motion sickness needs to be explored more. Schoettle and Sivak (2009) conducted a survey and reported that 61% of adults experienced motion sickness while reading, and almost 10% of the adults experienced serve motion sickness. 43% adults experienced motion sickness while viewing a video. Their survey also reported that people did not feel motion sick while they were looking out of the window, this clearly indicated the increase in motion sickness due to sensory conflict.

Morimoto et al. (2014) performed a study where they explored the difference in motion sickness perception while reading and watching a movie while in a moving car. Their results indicated that reading in a car induced motion sickness symptoms faster than watching the movie. If the increase in perception of motion sickness is solely due to sensory conflict then all of the activities should produce similar results of motion sickness perception regardless of a movie, reading or just playing a game. It would be interesting to explore different factors that may cause an increase in motion sickness perception. In that regard, this study aims to explore if mental demand is a factor that can lead to faster increase in perception of motion sickness. This information can help to develop motion sickness countermeasures, and also provide information to people susceptible to motion sickness about the tasks that might exacerbate the level motion sickness they experience in cars.

Chapter 4

4.1 Research question and Hypothesis

Based on the theoretical framework of the previous chapters, this thesis aims to study motion sickness by constructing the following research questions and hypothesis.

The first research question is formulated to study if there is a difference in motion sickness perception when performing two different tasks. Two tasks with varying degrees of perceived mental demand are used in this study to determine the effect of mental demand on the perceived level of motion sickness.

RQ1: Is the degree of perceived motion sickness higher on the task with higher perceived mental demand than on the task with lower perceived mental demand?

The hypothesis is formulated as follows:

H1: The high mental demand task induces a higher increase in perceived motion sickness scores than the low mental demand task in a real driving scenario.

From the theory in the previous section it is clear that EDA has a strong positive relationship with motion sickness. Therefore, in this study SCLs are used to measure the degree of motion sickness in a real driving scenario. SCLs are known to have a strong relationship with the measured motion sickness scores.

RQ2: Are skin conductance levels reliable objective parameters to measure the degree motion sickness experienced?

H2: Skin conductance levels increase with an increase in perceived motion sickness scores.

The next research question is exploratory and in relation with relative humidity and skin temperature. Skin temperature was reported to have an ambiguous relationship with motion sickness a few studies suggest that it increases with an increase in motion sickness and a few cite the exact opposite. This study expects that the ambiguity that is seen is literature could be due to the confounding effect of relative humidity. Based on the relationship between relative humidity and skin temperature (Atmaca & Yigit, 2006), it is expected that relative humidity strongly influences skin temperature.

RQ3: Can Skin temperature and relative humidity be used objective parameters to measure the degree of motion sickness experienced ?

H3: Relative humidity is strongly and positively related to skin temperature.

H4: Skin temperature and relative humidity increase with an increase in perceived motion sickness scores.

In addition, a mat attached on the passenger seat is used to measure skin temperature and relative humidity from the back of the person. This method is referred to as the non-invasive method in this report. The non-invasive method is used because in order to detect motion sickness in commercial cars a classical electrode kit that has electrodes clipped around a passengers finger is not ideal. Moreover, since the skin temperature is usually measured from the volar sites (palmar regions), this non-invasive method has to be validated because, in a thermo-neutral environment the temperature of the skin varies across the body. The temperature of the trunk is different from the temperature of the volar surfaces and the latter is usually lower (Bierman, 1936). Therefore, the fourth question is to validate the use of the skin temperature measured from the back to measure motion sickness.

RQ4: Does the non- invasive seat mat for measuring skin temperature provide reliable data as the classical electrode data collected from the finger?

H5: Skin temperature obtained with the non-invasive and classical electrode technique produces the same outcome in measuring motion sickness.

These questions and hypothesis are tested in this study by conducting a study that replicates a real driving scenario.

Chapter 5

This chapter outlines the details of the experimental design, participant selection, the methodologies used to answer the research questions.

5.1 Methodology

5.1.1 Participants

Participants were 19 male and 5 female employees at Volkswagen with a minimum age of 23 and a maximum age of 49. To be able to take part in the study the participants had to meet with various requirements and had to be completely healthy. The conditions were listed in a questionnaire (Appendix A) that was sent to them before they could be recruited to the study. The participants with physical impairment, cardiovascular weakness, hypertension (high blood pressure), hypotension (low blood pressure), epilepsy, balance disorders, pregnancy, other health impairments (e.g. flu-like infection) were excluded. This is done to ensure that motion sickness provocation did not affect any subject severely. All of the recruited sample fulfilled these conditions and signed an informed consent confirming their participation. The subjects were provided with a 20 euro gift voucher at the end of the study.

5.1.2 Experimental design

5.1.2.1 Study Design

This study has a within subject design, where the within subject condition is the low mental demand task or the high mental demand task. This study has four major sections, namely, the baseline measurement, task session 1, cooldown period and task session 2. The entire study was performed in a single day and therefore the order of the sessions are interchanged to avoid the effect of order. There is a cooldown period provided between task1 and task2 which helps subjects return to a motion sickness score of 0. The dependent variables are recorded throughout the entire duration of the study. It takes about 90 minutes from the start to the end of the trail.

5.1.2.2 Independent and dependent variables

The independent variable is the type of task whether is the watching movie or the high demand reading task. The susceptibility of the participant is another independent variable. When the participants were invited to the experiment they had to fill the motion sickness susceptibility score using the MSSQ. This score is used to label the participants as susceptible or non-susceptible based on their previous motion sickness experiences.

The dependent variables are collected throughout the duration of the study. There are multiple dependent variables the first is the subjective motion sickness rating that is measured every minute. The physiological variables, namely: EDA, skin temperature and relative humidity measured throughout the duration of the study are also dependent variables.

5.1.3 Scenario (motion sickness provocation)

This study replicates a stop and go scenario which is very common to occur in everyday traffic. This scenario is most likely to induce motion sickness in people. In the stop and go scenario used in this study an automated driving profile is used which lets the car accelerate and brake at random intervals. This profile is reproducible and the same profile is used across all the subjects. The subjects are given a tablet to perform a task in order to foster sensory conflict while driving in a stop and go situation, the tablet enables them to perform the tasks during the experiment trials. This scenario is a close representation of someone getting motion sick by using a tablet or a phone while they are in an everyday traffic situation (figure 5.1).

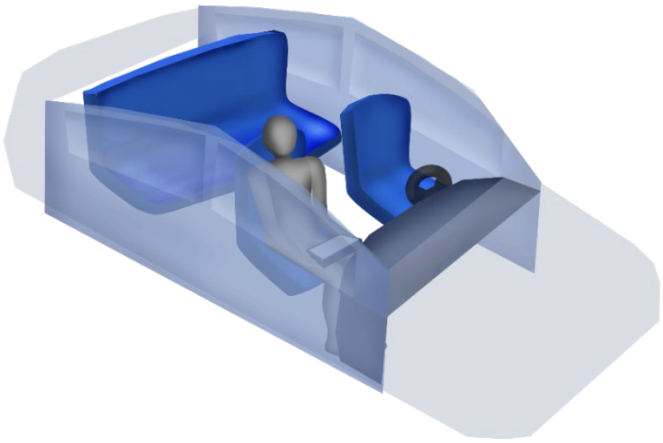

Figure 5.1 A representation of a subject with a tablet on the passenger seat of a car with a tablet

5.1.4 Mental demand task

The current research investigates the effect of mental demand on perception of motion sickness. The aim was to know if increasing the mental work load would then lead to a faster increase in the perception of motion sickness. The NASA- Task Load indeX (TLX) is used to measure the mental demand of a task. The NASA-TLX questionnaire is used to rate the task difficulty on 6 sub-categories with 21 point likert scale for each sub-category (Hart and Staveland, 1988), which is a common scale for measuring mental load. This scale has a mental demand sub category which is the most relevant for this study.

A pilot study was conducted to choose the task with a higher perceived mental demand on the NASA-TLX subscale for the actual experiment. In the actual experiment there were two tasks, namely the low mental demand task and a high mental demand task. The low mental demand task consisted watching a movie of a relaxing aquarium of fish, the task with a higher mental demand was to read a text and the subjects had to answer two questions from the text at the end. The reading task had a higher score on the NASA-TLX in the pilot study, hence it was chosen as the task with the highest mental demand.

5.1.5 Hardware and Software setup

The study design includes a real driving study that measured a EDA, skin temperature and relative humidity, while the subjects performed certain tasks on a tablet.

This study also measures EDA, skin temperature and relative humidity. There are two different types of physiological measurements made: 1. Traditional electrode method, 2. Non-invasive technique.

5.1.5.1 Traditional electrode measurement

The traditional electrode system measures physiology from the fingers, and measures skin temperature and EDA. The physiological kit used for this measurement is the biograph infiniti physiological kit by thought technologies. The skin conductance electrodes (sensor specification - P/N: SA9309M) are strapped around the pointer and ring finger of the non-dominant hand. The conductive part of the electrode is touching this palmar side of the hand. The skin temperature sensor (sensor specification- P/N: SA9310M) is placed on the middle finger and is secured by an adhesive tape around the middle finger. The thermistor is placed on

the palmar surface of the hand (figure 5.2). The hardware is connected to a laptop which runs the biograph infiti software to record the EDA and skin temperature at a frequency of 256Hz.

5.1.5.2 Non-invasive measurement technique

There is a sensor mat that is placed on the seat with 16 sensors placed on the mat. There are 10 sensors at the back and five at the upper leg to measure the skin temperature and humidity. There is one sensor attached near the head rest which measures the environmental temperature and humidity of the environment. More information about the software used to collect this data is provided in appendix C. The only comparable measurement between the invasive and the non-invasive technique is the skin temperature.

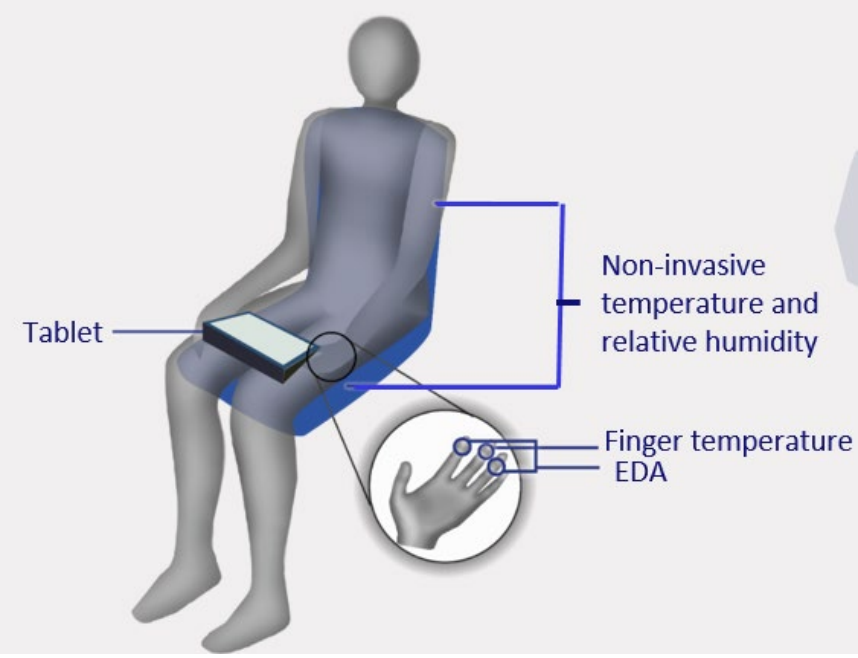

Figure 5.2 Model of the subject and the physiological sensors used in this study.

5.1.5.3 Other equipment

A google nexus tablet 10 with a 1.2 GHz processor was used to display the tasks on the tablet and simultaneously record the symptom level of the subject every minute (figure 5.3). The same software used to record the seat mat temperature is used to record the questionnaire data every minute (Appendix. C). R studio 3.4.1 is used for data analysis.

Figure 5.3 The display screen on the tablet presented to the subjects, with the task and the questionnaire

5.1.5.4 Subjective evaluation questionnaire for motion sickness

The example of the questionnaire that is used in this study is shown in figure 5.3. This questionnaire contains a symptoms rating 7 point likert scale based on the scale by Golding (2003). The labels of the scale used by Golding are very specific relating to nausea and vomiting (1 = no symptoms; 2 = initial symptoms of motion sickness but no nausea; 3 = mild nausea; 4 = moderate nausea; 5 = severe nausea and/or retching; 6 = vomiting). Not all motion sickness symptoms are experienced by everyone, therefore symptom specific scales can be very tricky to decipher for the participants. Also, not all the subjects experience nausea or vomiting , some may experience only severe head ache. Therefore, this study uses more generic labels that can be applied to all the symptoms experienced in common, so it is easier for the subjects to evaluate their symptom levels efficiently. The scale is relabeled as follows:

What is your current symptom level?

No symptoms	Beginning symptoms	Mild symptoms	Moderate symptoms	Severe symptoms	Very severe symptoms	Unbearable
0	1	2	3	4	5	6

The subjects are clearly explained the different symptoms they might experience during the study and they indicate the level of motion sickness on the questionnaire.

5.2 Procedure

Firstly, the subjects are invited to participate in the study and they are provided with documents which acquaint them with information about the study. They are also asked to send the MSSQ scores if they accept voluntary participation. They fill a demographics questionnaire and a driving experience questionnaire the day before participation. They are advised not to have any alcohol at least a day before participation.

The subjects are driven to the testing area where they receive information about the vehicle and measurement technology used in the current study. First, the formalities such as signing the informed consent, data consent are completed, the subjects are informed about the experiment and the symptoms they may experience during the driving scenario. The subjects are clearly informed that they can stop the trails if they do not feel very well. Otherwise the experimenters stop the drive once a motion sickness score of 4 is attained to avoid any serious symptoms. The subjects are seated inside the car with all the doors and windows closed throughout the study. They can however leave the if they do not feel like continuing or if they do not feel well.

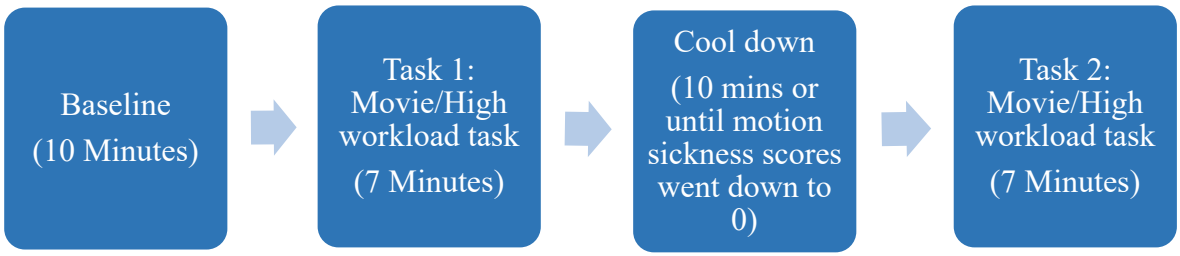

Figure 5.4 The experimental within subject design that is followed by all of the subjects.

Before starting the study it is important that the climate in the vehicle stabilizes to 23 degrees Celsius. This is the thermo-neutral environment at which the skin temperature should be recorded. After the initial procedures are completed the subject is equipped with the physiological sensors and is handed the tablet which is secured with a band around their leg so the tablet does not move during the study. Initially the baseline is recorded for 10 minutes. For this the subjects are asked to watch a relaxing movie in the vehicle for 10 minutes (at 23 degrees).

Once the baseline is completed, the first driving scenario starts, this lasts for 7 minutes. During the driving scenario the subject performs the high demand task or the movie on the tablet. They also indicated the motion sickness status on the questionnaire every minute. The trail ends at the end of 7 minutes or once the subject reaches a score of 4. The subjects answer the NASA TLX which evaluated the task on six task load characteristics on a scale of 21 points. At the end of the first trail a cool down period is initiated to help the subjects recover from their initial symptoms. The second trail is initiated once the subject reaches a score of 0. They are also verbally asked if they would like to proceed. They are asked to fill the NASATLX again.

5.3 Data analysis

5.3.1 Self-reported measures

The most important variable of this research is the subjective evaluation of motion sickness, which is the perceived motion sickness score every minute by the subject during the entire duration of the trial measured on a 7 point scale of 0-6. The motion sickness score is central and the most important measure in this study which talks about the state of the person at a given minute. The aim of the first research question is to investigate how the values of the subjective evaluation increase in the high mental demand task. For this, the motion sickness scores collected every minute during both the tasks are compared. The difference between the motion sickness scores between both the tasks are evaluated using a Non-parametric Friedman ANOVA test. The effect of mental demand is analyzed by correlating the highest achieved motion sickness score of each subject with the mental demand scores obtained from the NASA-TLX.

The motion sickness scores collected every minute during the study are used to evaluate the relationship of motion sickness with EDA, skin temperature and relative humidity. For

studying the changes in physiological variables during an increase in motion sickness symptoms, the physiological data is modelled over the motion sickness scores. In studies related to physiological variables, the physiological variables' pattern is studied over the time domain, that is to study if they are increasing or decreasing with time. However, in this study the physiological variables are studied over the subjective motion sickness ratings. This gives us an overview of the physiological variable when someone has no symptoms to how the physiology changes with an increase in motion sickness perception. Though the scale used is a 7 point likert scale (motion sickness scores 0-6), for ethical reasons the study terminates when a person reaches the motion sickness rating of 4 which is already moderate motion sickness experienced. Therefore the data collected only has data from 0-4 points on the scale. And since the duration of the trials was very short and the study also included non-susceptible people not many people attained the score of 4. Therefore, scores 3 and 4 are recoded as 3 for the data analysis.

5.3.1.1 Ordinal regression model

The relationship between the physiological variables and the motion sickness scores are modelled using an ordinal regression model. The motion sickness score is an ordinal variable since it is collected from an ordered scale. Therefore, an ordinal regression model is used in this study instead of a regular linear regression model. This study particularly uses the cumulative link mixed model as implemented in the *ordinal* package of the R software. It is one of the models in R which allows for random effects of predictors in ordinal regression (Christensen, 2018). When there is multiple measurements of the same individual involved the assumption of independence of observations is violated. Therefore, to account to this assumption a random effect is added (Schmidt, 2012).

A cumulative link model is used for observations that fall in a specific set of ordered finite categories. Ordinal observations are represented by a random variable that has to be predicted Yi that takes the value j if the ith (i- every subject) ordinal observation falls in the jth category and j = 1, 2, 3, …… j. θ_j is the threshold parameter or cut-point which is the probability of the ith variable falling in the jth category.

A basic cumulative model described by Christensen (n.d. , p. 2) is, $\gamma_{ij} = F(\theta j - (xi)\beta)$. Where, $\gamma_{ij} = P(Y_i \leq j) = \pi i1 + \cdots \pi ij = 1$, are the cumulative probabilities, xi is a vector of predictor variables, β is the intercept and F is the logit link function. The thresholds θj are ordered and $-\infty \equiv \theta_0 \leq \theta_1 \leq \ldots \leq \theta_{j-1} \leq \theta_j \equiv \infty$.

This model is similar to the logistic regression model, which models outcome variable as a log of its' odds, represented by $logit\big(P(Y_i \leq \text{j})\big) = log\ \frac{P(Y_i \leq \text{j})}{(1-P(Y_i \leq \text{j}))}$. The odds represent a likelihood of an outcome variable Y in a category j, given a vector of a variable X. Unlike probabilities which range from zero to one, odds range from 0 to infinity. In order to understand odds better, the example of success and failure is used. Imagine, the probability of success is p = .8, the odds of success would then be defined as, p / (1-p) = .8/ 1-.8 = 4. Therefore, the odds of success are 4 to 1. In summation, odds are computed from probabilities and explain the likelihood of an event occurring. Odds are commonly used in logistic regression models, except the model produces the log of the odds of the outcome variable Y.

The cumulative link mixed model can be used to define a random effect, by letting the random coefficients have random slopes and intercepts. Equation 5.1 represents the model that is used in this study, Y is the motion sickness level from a category of zero to three, X are the physiological variables (EDA, Skin temperature and relative humidity), the random variable is the ID of the person.

$$logit(P(Y_i \leq \text{j}) = \ \theta_j - \ \beta_i(Xi) - v(Random_i)$$

$$i = 1, \ \ldots\ldots, n, \quad j = 1, \ \ldots\ldots, j-1$$

Equation 5.1. Equation of the ordinal regression model

The logit function calculates the log odds of the Y variable belonging to a higher category j. The interpretation of this model is similar to a regression model, for instance β of EDA is 1.5, this implies that one unit increase in EDA results in a 1.5 unit change in the log of the odds of the motion sickness level belonging to a higher category. The log can be removed by taking the exponent of the β coefficient, which produces the odds of the variable.

5.3.2 EDA

EDA is collected from the palmar surface of the pointer and ring finger of the non-dominant hand, there were only right handed subjects in the study. EDA was collected at 256 HZ frequency. The Skin conductance levels are obtained from the EDA by down sampling and filtering the tonic signal out by smoothing EDA the curve using a down sample filter at 10 Hz using the software.

The EDA collected varies from person to person, therefore it is normalized to deal with large individual differences. There are a number of ways to normalize EDA, in this study normalization is done with the mean of the baseline, using the following equation (Meusel, 2014):

$$Normalized\ EDA = \frac{Single\ data\ point - mean\ of\ baseline}{Mean\ of\ baseline}$$

Equation 5. 2. Normalization of EDA

5.3.2 Skin temperature

The skin temperature is collected from the volar surface of the finger, and it is also measured non-invasively using a seat mat (figure 5.2). Skin temperature is also measured at a frequency of 256Hz . The data is saved with the same frequency and then the change in skin temperature is calculated. The difference in skin temperature is calculated using equation 3. The same procedure is followed for the skin temperature from the finger and also from the temperature collected from the non-invasive seat mat. The seat mat had 16 sensors, however only 8 of them which had a constant contact with the person's body was considered for data analysis.

$$\Delta Skin\ temperature\ = (Single\ datapoint - Mean\ of\ baseline)(℃)$$

Equation 5.3. change in skin temperature

5.3.2 Relative Humidity

The relative humidity is measured non-invasively using a seat mat attached to the passenger seat using the sensors also used to measure the skin temperature from the seat mat(figure 5.2). The change in relative humidity from the baseline is calculated using the formula in equation 5.4.

$$\Delta relative\ humidity\ (\%)\ = \frac{Single\ datapoint - Mean\ of\ baseline}{Mean\ of\ baseline}\ X\ 100$$

Equation 5.4. change in relative humidity

Chapter 6

This section contains all the relevant details about the results from the data analysis.

6.1 Effect of mental demand on perceived motion sickness scores

To study the effect of mental demand on perceived motion sickness scores, at first the NASA-TLX scores were obtained and analyzed. The ratings were obtained for both the tasks, and it is visualized below in figure 6.1. The reading task had a higher perceived mental demand than the watching movie task. On average the subscale ratings were higher on the reading task.

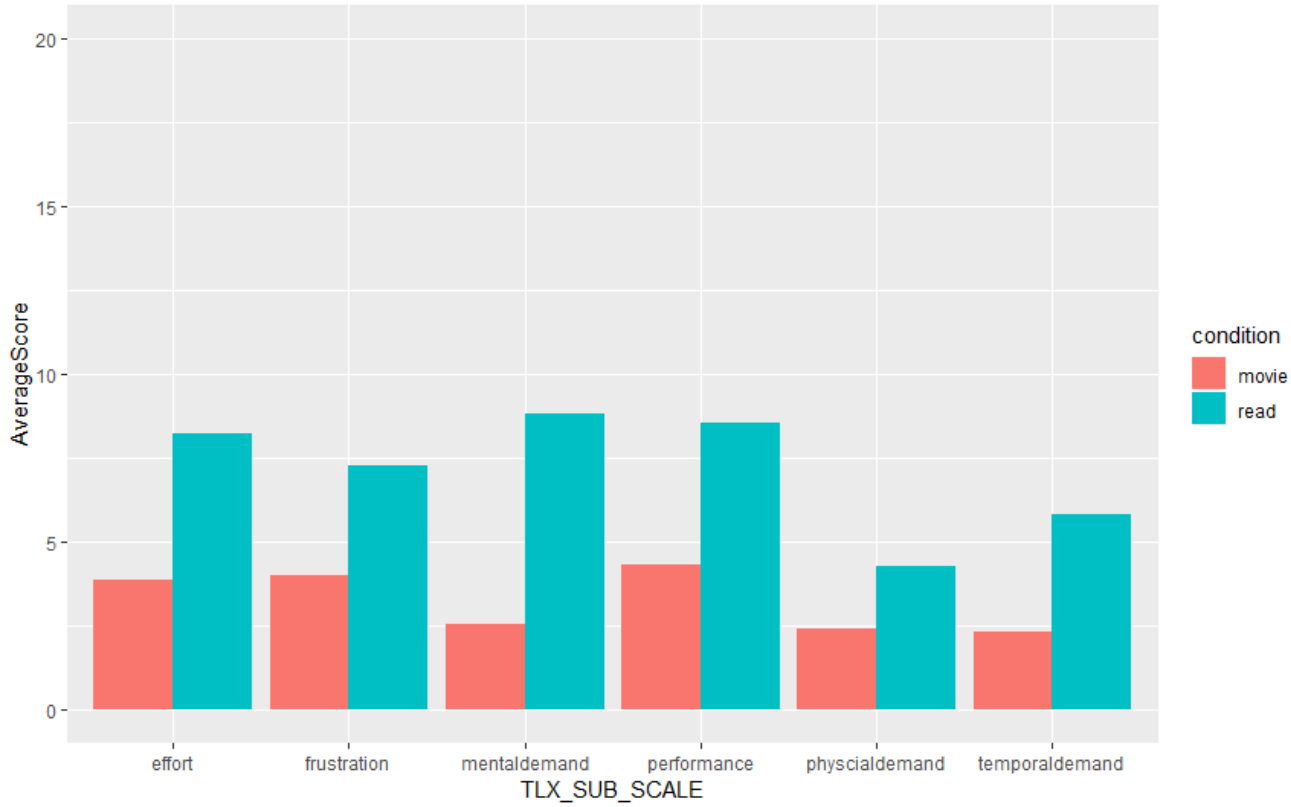

Figure 6.1 NASA-TLX scores obtained after the trail from each subject

TLX Subscale	M(SD) movie	M(SD) read	P-value
Mental demand	2.521(1.85)	8.82(4.73)	<0.001***
Physical demand	2.39(1.87)	4.62(4.34)	0.06
Temporal demand	2.30(2.30)	5.82(4.19)	0.001*
Negative Performance	4.30(2.83)	8.52(5.23)	0.001*
Effort	3.87(2.73)	8.21(5.41)	0.002*
Frustration	4.00(3.86)	7.27(6.00)	0.03

Table 6.1 Some descriptive statistics and T-test results of NASA-TLX scores (significance level α= 0.008)

Table 6.1 contains the means standard deviation of the two tasks. On average, the reading condition had a higher score on all the subscale categories but not to a statistically significant extent on the physical demand. Individual t-tests were performed to test the significance of these scores. Since six tests are being performed consecutively, the significance level of the alpha value has to be adjusted using the Bonferroni correction. The single step approach to doing this is α/ Number of tests. Therefore, 0.05 / 6 = 0.008 is the new alpha level. The mental demand for the movie (M=2.52, SD= 1.85) and the reading (M= 8.82, SD= 4.73) was statistically significant with t(28) = -5. 94, p < 0.008. The only non-significant scores were temporal and physical demand (Table 6.1).

The difference in the perception of motion sickness between both the conditions is indicated in figure 6.2. An Analysis Of Variance (ANOVA) was used to assess the difference in perception of motion sickness between both the conditions. However the data are not following a normal distribution, therefore a non-parametric alternative of the ANOVA is run, a Friedman's ranksum test. The Friedman's test of differences indicated a rendered chi-squared value of 1.470 was significant p< 0.01. The difference in perception of motion sickness between both the groups are statistically significant.

The effect of mental demand on the perceived motion sickness scores is calculated using a regression in which the highest achieved motion sickness scores of each subject is correlated

with their perceived mental demand score collected from the NASA-TLX averaged across all subjects. In the reading condition, the correlation of the perceived mental demand from the NASA-TLX and the motion sickness score is r= 0.07. In the movie condition the correlation between the mental demand and the motion sickness score is r=0.02. There is a perceived difference in the motion sickness scores between both these tasks, however, it cannot be explained by the difference in perceived mental demand.

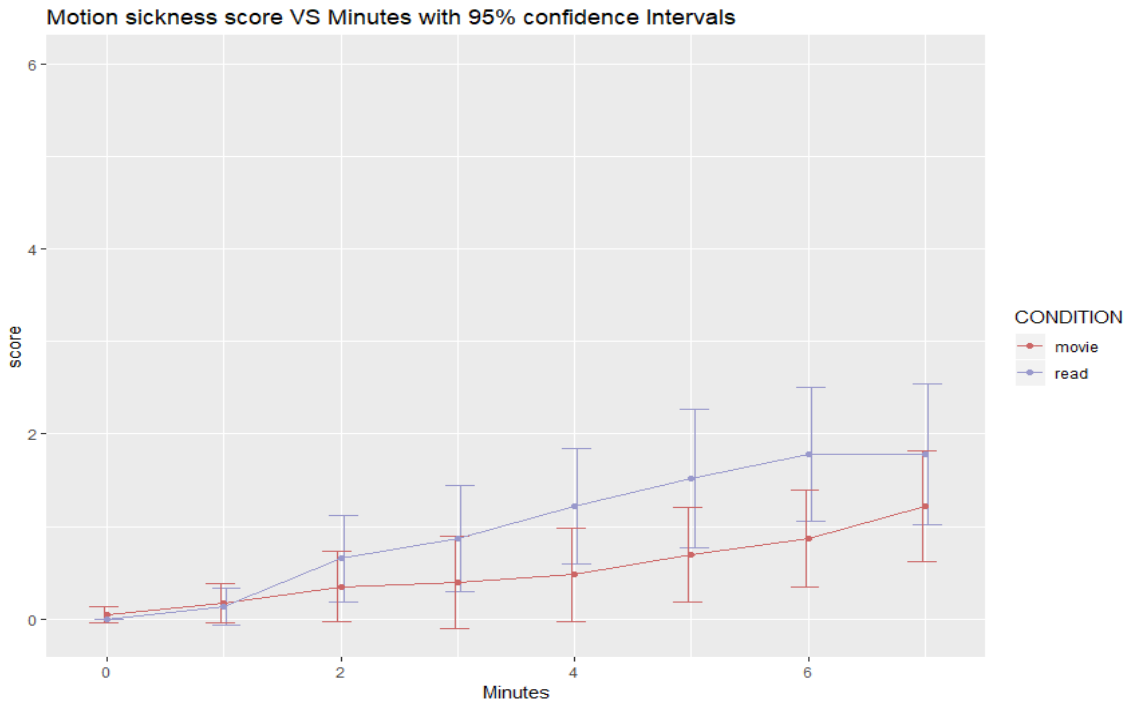

Figure 6.2 Difference in motion sickness scores between both the experimental conditions

6.2 Measuring motion sickness with EDA

EDA has been a strong and positive predictor of motion sickness. This study tries to study the relationship between skin conductance levels and the perceived motion sickness scores. The explanation on how the skin conductance levels are obtained are mentioned in chapter 5. Figure 6.3 illustrates the results for the average EDA values of all the participants modelled over the four levels of motion sickness scores. The average value seems to be increasing as people start feeling more symptoms. Skin conductivity levels show an increase if the perceived symptoms are higher.

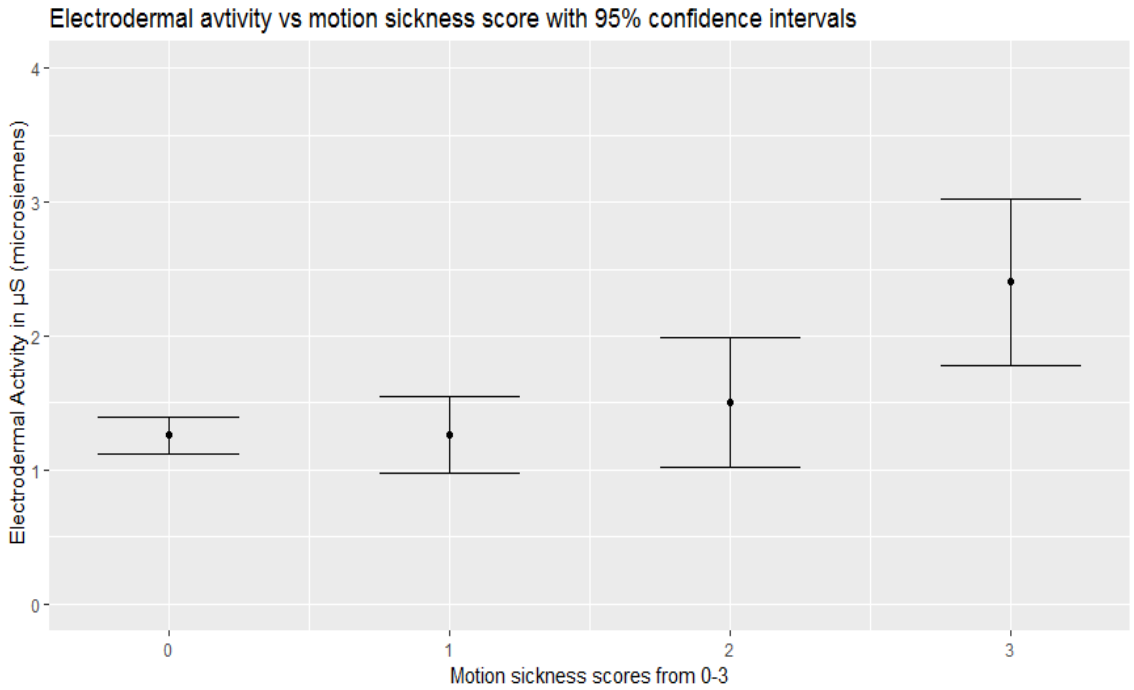

Figure 6.3 EDA represented over motion sickness scores of 0-3. The scores were obtained on a scale of 0-6, but the maximum level was set at 4. Levels 3 and 4 are expressed as level 3.

Ordinal regression was conducted to study the relationship between skin conductance levels and the perceived motion sickness symptoms. This model treats ordinal data with unequal responses in each category and also predicts the maximum likelihood of an EDA value occurring in a one of the categories of the categories of the symptom levels. The model is fit with the following equation:

$$logit(P(Y_i \leq \mathrm{j}) = \theta_j - \beta_1(EDA_i) - v(ID_i)$$

$$i = 1, \ldots\ldots, n, \;\; j = 1, \ldots\ldots, j-1$$

Equation 6.1. Cumulative link model equation for EDA and person ID as random effect.

The model predicts the motion sickness symptom score using the EDA values, and the person ID as a random effect to the model. The ordinal regression model is run, the summary of the model contains the maximum likelihood estimates of the parameter:

$$\beta_{EDA} = 0.43,$$

$$\theta j = [1.4, 2.6, 3.3]$$

The beta coefficient for EDA is positive on average, indicating that at higher the perceived motion sickness symptom level is higher. The p value of EDA is p = 0.0008 there is a significant effect of EDA on the motion sickness scores. The significance of the random effect is testing using a likelihood ratio test with an ANOVA, the effect of the person is significant with Pr(chi2) = 0. The variance of the model explained by the random effect of the person is υ= 2.17.

The odds of observing the EDA in motion sickness score categories are calculated using the exponent of the beta coefficient from the model exp(0.43). For every microsiemens increase in EDA, the odds of observing motion sickness score category 0 vs. any other higher category increases by 51%.

6.3 Relationship between skin temperature, Relative humidity and motion sickness

The next research aim was to identify the relationship between relative humidity and skin temperature in the context of motion sickness. During data collection from the seat mat, data of 7 subjects was not recorded, therefore for this section participants were N=17 * 2 (two sessions). According to the thermoregulatory mechanism in high relative humidity conditions the temperature of the skin increases. Figure 6.4 represents the relative humidity and the skin temperature values recoded from the non-invasive seat mat plotted against the motion sickness values.

On performing a Pearson correlation between the temperature and the relative humidity that is collected from the seat mat non-invasively, the results indicated no association between the two variables. The results showed a weak negative association between skin temperature and relative humidity around the area of the skin (r(256) = - 0.13, p = 0.07), and the p value was not significant. Therefore, there can be no relationship assumed between the relative humidity and the skin temperature collected non-invasively from the seat mat.

The relationship of change in relative humidity from the baseline with motion sickness is still explored using the ordinal regression model. The $\beta_{relative\ humidity} = 0.01$ of relative

humidity was not statistically significant, p=0.10. Relative humidity is found to have no significant relationship with motion sickness.

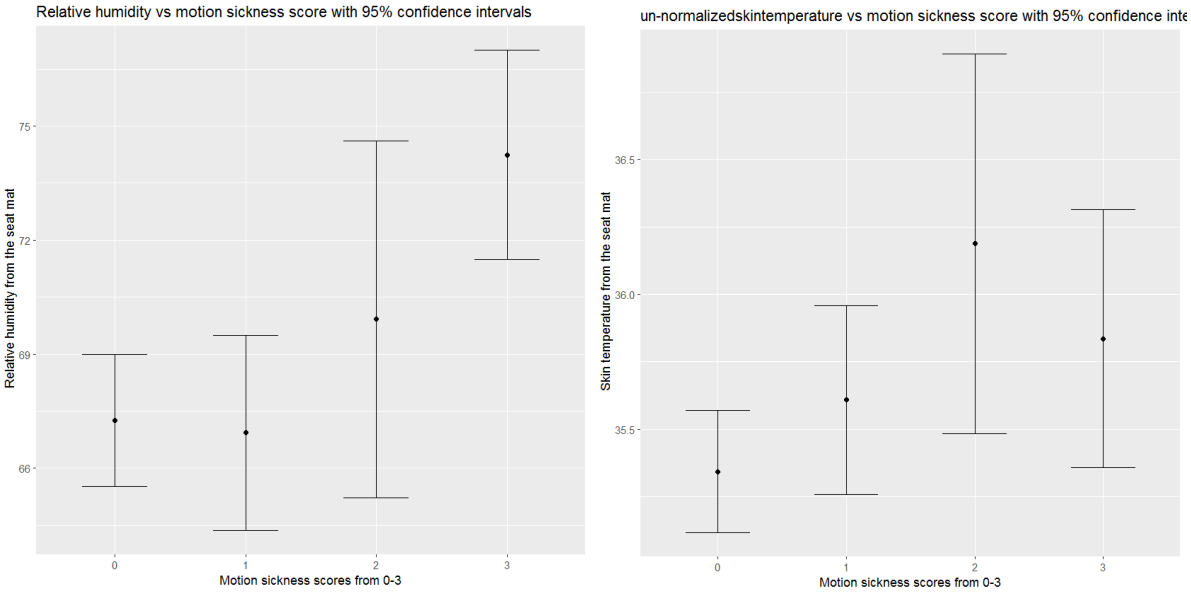

Figure 6.4. Relationship of non-invasive skin temperature and non-invasive relative humidity over motion sickness scores.

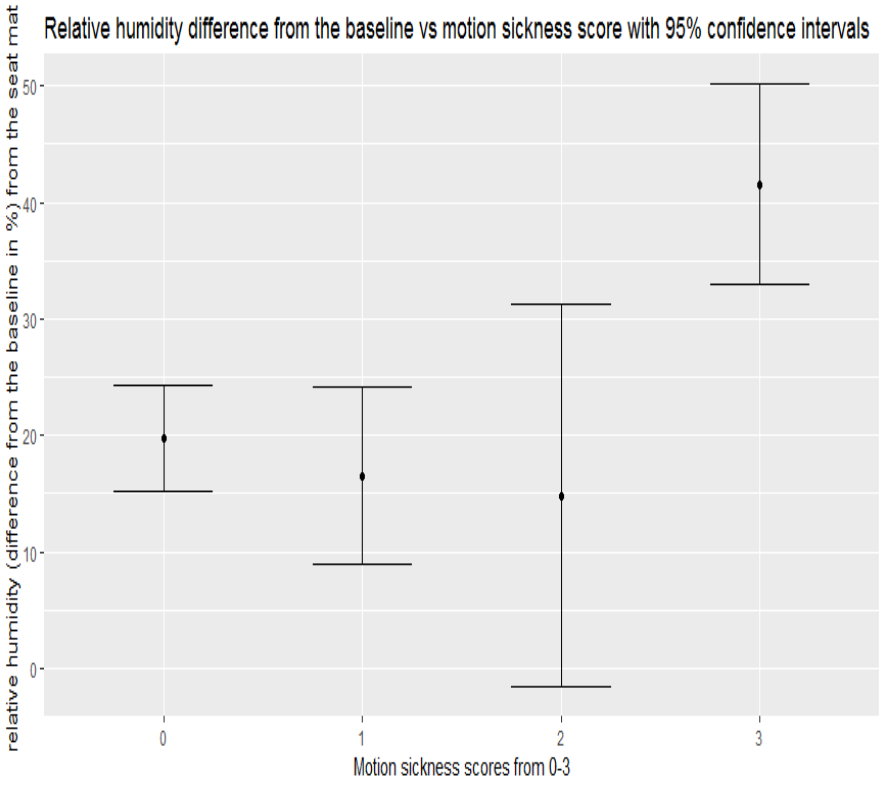

Figure 6.5. Change in relative humidity from the seat mat represented over motion sickness scores of 0-3. The scores were obtained on a scale of 0-6, but the maximum level was set at 4. Levels 3 and 4 are expressed as level 3.

Figure 6.6 represents the change in skin temperature from the baseline measured non-invasively and it is increasing with an increase in motion sickness. This relationship is further explored using the ordinal regression model.

$$logit(P(Y_i \leq j) = \theta_j - \beta_1(\Delta non - invasive\ skin\ temperature_i) - v(ID_i)$$

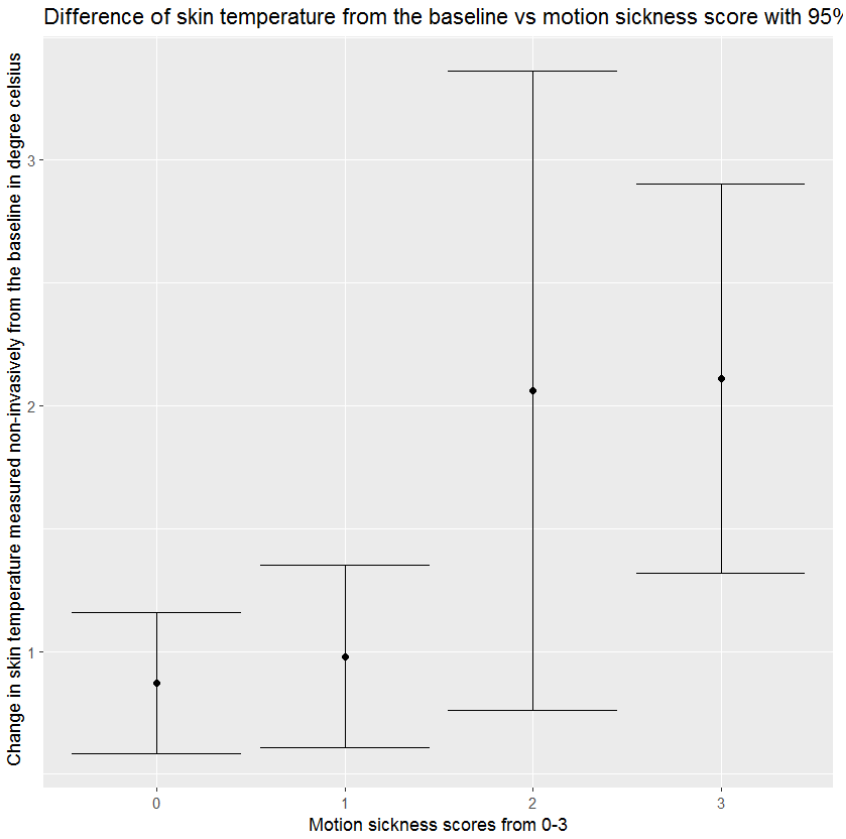

Figure 6.6. Change in skin temperature from the seat mat represented over motion sickness scores of 0-3. The scores were obtained on a scale of 0-6, but the maximum level was set at 4. Levels 3 and 4 are expressed as level 3.

$$\beta_{\Delta non-invasive\ skin\ temperature} = 0.45$$

$$\theta j = [2.6, 4.1, 4.9]$$

The $\beta_{\Delta non-invasive\ skin\ temperature} = 0.45\ , p = 0.01$, is the coefficient of the non-invasive skin temperature that is measured as a difference from the baseline. It increases positively with motion sickness and also has a significant effect on motion. For every degree Celsius increase in skin temperature measured non-invasively from the odds of observing category score 0 vs. a higher category of motion sickness score increase by 56%. The variance of the model

explained by the random effect of the person is υ= 0.89 and the random effect of the person is significant with p(chi2) = 0.

6.4 Invasive vs Non-invasive skin temperature measurement

Figure 6.8 visualizes the relationship of both the finger temperature and the non-invasively collected temperature from the back. The figure shows that the two temperature measurements are different from each other, the non-invasive temperature increases with an increase in motion sickness levels while the temperature collected from the finger decreases with an increase in motion sickness scores. This indicated that both the temperatures are not the same and the invasive and non-invasive technique do not quite measure the same differences in temperature. The results of a Pearson correlation indicated (r= -0.13, t(256)= -2.51, p= 0.03) a negative correlation.

A ordinal regression model is again used to study the relationship between the finger temperature and motion sickness perception. The model showed that there effect of motion sickness status on the temperature that is collected from the finger is not significant. With the $\beta_{\Delta finger\ temperature} = -0.311, p = 0.10$, it is clear that there is no significant relationship between the finger temperature and the motion sickness status. The negative coefficient indicates a negative relationship between motion sickness and finger temperature. Similarly, the $\beta_{\Delta non-invasive\ skin\ temperature} = 0.45\ , p = 0.01$ is the coefficient of the skin temperature difference from the baseline that is measured non-invasively, it has a positive increase and is statistically significant. Since both the temperatures measure motion sickness differently, the hypothesis that the finger temperature and non-invasively collected temperature at more or less the same level is not supported.

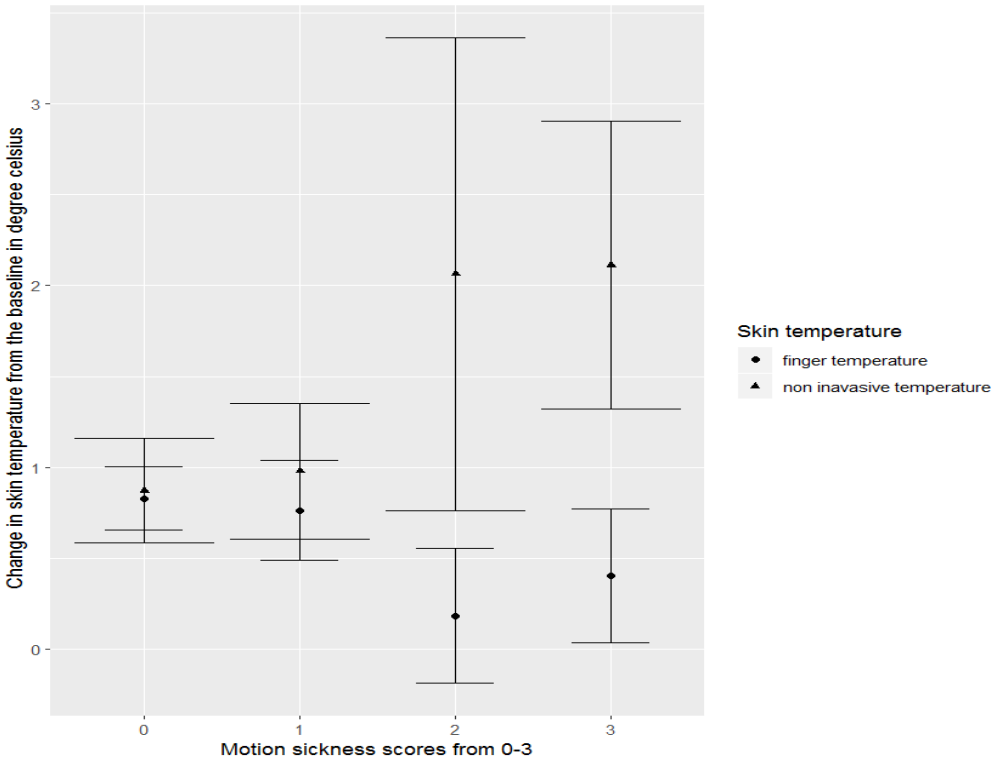

Figure 6.8. Relationship of non-invasive skin temperature and finger temperature measured over motion sickness scores.

Chapter 7

7.1 Discussion of results

In the current study, we investigated the occurrence of motion sickness by means of self-reported measures under two different experimental conditions with varying mental demand. Then we also explored the relationship of motion sickness with EDA, skin temperature and relative humidity. In the first study, the difference in motion sickness perception during a seven minute stop-and-go driving scenario was tested while the subjects performed two different tasks with varying mental workload, which was measured using the NASA-TLX task characteristics questionnaire. The main findings are summarized below.

The aim was to explore if mental demand can influence the increased perception of motion sickness scores. It was hypothesized that with an increase in mental demand there is an increased perception of motion sickness. To explore this a within-subject study with two different tasks was used. The results showed that, although there was a statistically significant difference between the two tasks, however, mental demand cannot explain this difference in motion sickness perception. One possible explanations for mental demand not explaining the difference between both the tasks could be that the type of information presented in both the conditions were different. The reading condition presents static information while the movie condition provides dynamic information. In this regard, eye movements can be used as a factor to possible explain the difference in motion sickness perception between both the tasks.

The second aim of the study was to verify the relationship between EDA and motion sickness scores. It was hypothesized that EDA increases with an increase in motion sickness. The results indicated a positive relationship as hypothesized, with an increase in one unit of EDA the odds of observing an increase in the motion sickness score increases by 51%. The individual differences were however high in this case, the model on adding the person as a random effect was statistically significant from the model which did not have the random effect added.

The results from the EDA suggests that it is a very good predictor of motion sickness for most people, when modelling motion sickness prediction EDA, it can be used to say that an increased activity in EDA suggests that the subject is motion sick.

The third research aim was to study the relationship between relative humidity and skin temperature and to study if they can be used to measure motion sickness. It was hypothesized that relative humidity and skin temperature are strongly and positively related to each other. In contrast, there was a weak negative non-significant relationship between relative humidity and skin temperature measured from the non-invasive seat mat.

The fourth hypothesis was with regard to the relationship of skin temperature and relative humidity with motion sickness. The non-invasive skin temperature collected from the seat mat increased significantly with motion sickness. With an increase in every degree Celsius of the skin temperature collected non-invasively the odds of observing a higher category of motion sickness score increases by 56%. Relative humidity had a very small positive increase with an increase in motion sickness scores, however it was not statistically significant.

The hypothesized relationship between skin temperature and relative humidity was not supported by the data. In motion sickness the thermoregulatory mechanism of the body behaves differently than normally due to the cooling down of the core body temperature (Nobel, 2010). The core body temperature and the skin temperature are inversely proportional to each other. This could explain why the skin temperature increased at the back increased, while the temperature at the finger decreased .

Additionally, the relative humidity was also used to study the change in sweat content of the body therefore it was expected to increase with an increase in motion sickness. However, relative humidity is defined as the ratio amount of moisture that is present at a given moment to the saturation vapor content at a given temperature. Therefore, the absolute humidity which is the amount of moisture at any given point in time, has to be measured to study the sweat content from the body. In summation, due to the change in thermoregulatory mechanism during motion sickness relative humidity may not have any relationship with skin temperature and also there was no significant relationship with motion sickness.

Lastly, in this study, the finger temperature and the non-invasive temperature did not show the same degree of changes with a change in the degree of motion sickness. The finger temperature reduced with an increase in motion sickness but it was not significant. Bertin et al. (2004) collected skin temperature from the palmar region of the body. They found a decrease in skin temperature at the palmar region with an increase in motion sickness. Motion sickness leads to the cooling of the core temperature (Nobel, 2010) and this should lead to an increase in skin temperature, as hypothesized. But there was a decrease in the finger temperature at the finger.

In retrospect, Brajkovic, Ducharme and Frim (2001) showed that the finger temperature is very strongly correlated with the core temperature of the body. It is probable that the core cooling is reflected by the reduction in finger temperature. Therefore, the finger temperature could have decreased with an increase in motion sickness due to the cooling of the core temperature. However, the reduction in finger temperature was not significant in this study. In summation, the hypothesis made in this study about the skin temperature measured at the finger and the skin temperature from the back producing the same outcome was not supported.

7.2 Limitations and Recommendations

The first drawback of the study could be that it followed a within-subject design and the subjects performed the trails one after the other on the same day. Since physiological data is measured in relation to motion sickness perception, a within-subject study can measure people on two different days. Mental demand did not affect motion sickness perception, therefore, other confounding factors should also be measured. For instance, the effect of eye movements, were not measured in the study. Eye movements could be a factor which cause an increased perception of motion sickness. This could further help to explain why people got more motion sick in the reading task.

The study measured the thermo-regulatory responses of the body during motion sickness through skin temperature and relative humidity. For this, a thermo-neutral environment at 23-27 degree Celsius was needed to avoid fluctuations in skin temperature data. However, maintaining this temperature was not possible. Subjects sometimes wanted to open the window or reduce the temperature in car. The environmental temperature was not stable at all times. In the future studies, the temperature in the car should always be maintained at a 23 degrees and the windows should not be opened to measure reliable data.

Another limitation of this study was the sample size, though at first the study was made with 24 subjects with 2 sessions each. The non-invasive measurement of 7 subjects were not available due to a problem with the measuring software. The use of faster computers with a more reliable data collection software could help from not losing data. In addition, a proper power analysis was not performed to determine the sample size of the study, future studies should determine samples using a priori power analysis.

Also, the future models of motion sickness should take into account other contributing factors such as time, susceptibility and gender differences. These factors can help to make more well defined models. The core temperature was not measured in this study, therefore, conclusions about skin temperatures cannot be made. This study did not study the all the variables with relation to thermoregulatory mechanism, core temperature of the body was one variable that wasn't included in the study. The inclusion of core temperature it could be useful to make general conclusions about the thermoregulatory mechanism of the body during motion sickness.

Finally, in this study relative humidity did not have a significant effect on motion sickness. The value that should have been studied with respect to sweat is absolute humidity. Relative humidity does not measure the actual sweat content of the body and may not be useful to describe the relationship with motion sickness. Perhaps, future studies should include absolute humidity of the body to study motion sickness.

Chapter 8

8.1 Conclusion

The present study showed how motion sickness perception is not affected by a change in mental demand. A study with two tasks was conducted one task with a low mental demand and another with a high mental demand. During these EDA and finger temperature were measured using a classical electrode kit. A non-invasive seat mat was used to measure relative humidity and skin temperature from the back of a person. The main aim was to study the effect of mental demand on changes in motion sickness scores between the two tasks of varying mental demand. In addition, the relationship of the measured physiological attributes and subjective motion sickness was studied. The main findings are summarized as follows:

- Subjects experienced motion sickness faster on the reading task than the movie task, but this difference likely is not explained by a difference in the mental workload associated with these tasks.
- Skin conductance levels increased with an increase in motion sickness.
- Skin temperature measured from the finger reduced with an increase in motion sickness but was not statistically significant.
- Relative humidity and the skin temperature measured non-invasively from the same place of the body (back and upper thigh) did not correlate with each other.
- The skin temperature measured non-invasively from the back and upper thigh using a seat mat increased with an increase in motion sickness and the effect was significant.
- Relative humidity was not affected by motion sickness.
- The finger temperature and non-invasive temperature did not correlate and also they measured motion sickness differently.

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