CHALMERS

Motion sickness in cars

Physiological and psychological influences on motion sickness

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Gothenburg, Sweden, 2012

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Bachelor of Science Thesis on behalf of Volvo Cars

Acknowledgements

We would like to thank our supervisor Magnus Lindh at Volvo cars for his help during this project. We would also like to thank our supervisor Sven Ekered and our examiner and supervisor Hans Eriksson at Chalmers University of Technology in the department Product and Production Development, for their help and feedback. We wish to thank all the people at Volvo Cars for taking the time to share their valuable information and the researchers and lecturers that have helped us during this project. We would also like to thank participants of the focus group and interviews for sharing their thoughts and experiences with us.

Abstract

Motion sickness is a common problem and many need to replan their trips because of their own symptoms or because their children are affected. Motion sickness can occur on practically anything that moves; boats, airplanes, cars and amusement rides etcetera. Although this thesis involves research from many different areas, it is focused on the car industry.

This thesis is made on behalf of the Body and Trim department on Volvo Cars. The main purpose was to find facts of motion sickness in different vehicles and situations and to find areas of improvement. Another purpose was to investigate the possibilities of creating a market offer for a motion sickness reducing car and to design a symbol for feedback to the driver to decrease driving behavior that could cause motion sickness.

Information gathering was undertaken through literature studies of reports, disquisitions, articles and patents. Meetings were held with employees at Volvo Cars and researchers. As a more subjective source of knowledge interviews have been held with individuals suffering from motion sickness and a focus group was held to gain ideas and thoughts from possible customers.
The retrieved information shows a wide variety of different factors contributing to motion sickness: air quality, smell, temperature, taste, vibrations, visual input, oxygen ions, stress, sound, head alignment and body posture. After the second scope, four areas were chosen to conduct further studies on: oxygen ions, infrasound, vibrations and design of a feedback symbol.

A conclusion drawn was that a market offering is not preferred. Due to the large individual differences it is almost impossible to guarantee a car that does not cause motion sickness. Because of the psychological and individual factors, it would be beneficial to include a feedback symbol in a bigger context to shift focus from motion sickness, which in other case could cause stress among the passengers due to the psychological involvement.

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1. Introduction

1.1 Background

Volvo Car Corporation is one of the strongest brands in the automotive industry and has a long history of leading innovations (Volvo Cars). In 2010 they had over 13 000 employees in Sweden and a turnover of 102 billion Swedish kronor (Allabolag.se, 2012). Volvo's core values are quality, design, safety and environment (Volvo Cars).

This project is made on behalf of the Body and Trim section at Volvo Cars Corporation. Volvos goal with this project is to minimize the causes to motion sickness in Volvos cars in order to gain additional sales arguments. There are very few inventions today regarding motion sickness made by the car industry and the existing research is foremost oriented on marine transportation, trains and military vehicles. The connection with cars is therefore a relatively unexplored area within the car industry which will possibly increase Volvo's economical profits since they would be one of the first car companies to penetrate this market. In order to find possible ways to improve a car in aspects of motion sickness, it is necessary to do research in literature and known areas regarding this subject.

Motion sickness is a problem that affects many people and there is a need among customers to minimize the causes of this in cars since there are many who are dependent on the car as means of transport and struggle to piece together their everyday life, mainly because of motion sick children. Sometimes it is needed to go by night when the children are asleep instead of travelling during the day. Design is often a higher priority than comfort and ergonomics, which in some cases can make the car worse from a motion sickness point of view (Johansson, 2012).

The susceptibility to motion sickness varies widely and does not affect all in road transportation (Griffin, 1990. p.271). A survey made on 300 undergraduates showed that 58% had experienced motion sickness when travelling by car and 33% had vomited as a result of car sickness before the age of 12 (Griffin M. , 1990, p.318). Many symptoms of motion sickness are hard to detect and they appear long before symptoms such as nausea and vomiting. Those precursors can impair performance and can make the affected person feel indifferent to what is going to happen. They are often harder to perceive and consists of short term memory impairment, fatigue and a reduced capability to perform tasks (Griffin, 1990. p.273).

The symptoms of motion sickness are similar regardless of the stimuli that cause it, but are named many different things depending on where it occurs. Motion sickness can be called: sea sickness, car sickness, air sickness, space sickness, travel sickness and simulator sickness. If a person is exposed during a long time and if he/she is medicated, adaptation to motion sickness usually occurs within 48 hours (Dahlman, 2009).

1.2 Purpose

There are three purposes of this project. One major purpose that occupies a big part of the work, and two minor purposes:

The main purpose is to find facts of motion sickness, connect the contributing factors to Volvo's cars and develop concepts and recommendations that can minimize or eliminate motion sickness. Another purpose is also to design a symbol that can be used in the car to inform the driver when the frequency that affects the driver reaches 0.2 Hz since this was found to be a motion sickness inducing frequency in Volvo's pilot study. It will also be examined whether it is possible to develop a market offer that comprises a car that reduces motion sickness.

1.3 Objective

The aim with this project is that the developed concepts and recommendations shall be integrated in Volvo's cars. The desired effect is to make the customers feel well while driving and travelling as a passenger with none, or reduced, experience of motion sickness.

1.4 Scope

The project will not involve execution of empirical tests but empirical studies that already exist within the area motion sickness will be investigated. Research about medical solutions that are used with the purpose to minimize symptom of motion sickness will not be investigated due to a desire to minimize the use of medicines.

2. Theoretical reference frame

The symptoms of motion sickness are very similar regardless of the situation or stimuli that cause it, and it is a commonly occurring problem to many people. Researchers have noticed and investigated motion sickness for a long time and much research has been made with regard to vehicles like: airplanes, space shuttles, trains, cars, vehicles in the military and the main object of study have been marine vehicles. However, there are little published studies made on low frequency motions in cars (Griffin M. J, 2004).

Most of the found facts in this project are from studies made by Michael Griffin, Geoff Leventhall and Joakim Dahlman and remaining sources have been taken from meetings, Chalmers library databases and a few other websites found through the search engine Google. M.J Griffin has done extensive research within the area of vibrations, H.G. Leventhall within the area of low frequency sound and Joakim Dahlman has done most of his research regarding motion sickness within the marine transport area.

Views on which solutions that are favorable in order to minimize the risk for motion sickness differ amongst researchers. Some believe that it is good to shield the periphery while travelling in a vehicle, while some think that it is best to have as wide field of view as possible. According to a test made by Turner and Griffin in 1999, it is beneficial to have a good frontal view and many researchers agree that it is preferred to focus on the horizon in order to prevent nausea. In this project, it is assumed that it is most beneficial to see as much as possible in a car, but with focus on the horizon and frontal view. Although many have different opinions on how to prevent motion sickness from occurring, most researchers seem to agree on the fact that the psychological factors play a major role in motion sickness.

3. Research questions

Some questions and ideas have already been raised by Volvo and some questions have been raised by the authors of this report. Most of the questions origins from the beginning of the project and some were raised during the project. Below, questions that have been answered in this project are categorized by different subject areas.

	Volvo	Authors
Vision	Would it be beneficial to have: • Good visibility forward and sideways? • Low beltline? • Thinner A-pillar? • Thinner B-pillar? • Integrated child seats placed high (Higher than they are today?) in order to create more visibility for the passengers? • A shedable headrest in order to create more visibility to the backseat passengers?	• Is it worse to look out the window in a 90 degree angle than straight ahead? • Can you become motion sick when you are asleep? • What individuals suffer most from motion sickness?
Proprioception	Would it be beneficial to have: • A feedback symbol when frequencies are close to 0.2 Hz? • Hard padded chairs with side supports? • Side support for the head? • An upright sitting position? • Things and buttons higher up so you do not need to lean forward in order to reach them?	• How many suffers from pre-stages to motion sickness?
Travelling		• How much influence do the pre-stages of car sickness pose from a performance perspective when it affects the driver? • How much depends on physical

		factors and how much depends on psychological when motion sickness occurs? • Is there any other research made on motion sickness other than within the marine, train and military area?
Taste		• Can car sickness become worse if a person eats after feeling sick (because the orifice of the stomach closes)?
Ears	• Can sound trigger nausea?	• Can the organ of equilibrium be affected by sound/ sound absorption? • Is there any audio frequency that can soothe the feeling of nausea? (Many people feel negatively affected by infrasound just before a thunderstorm; can ultrasound have the opposite effect?)
Vibrations	• How much influence does the way of driving have on motion sickness? • How often does the frequency 0.2 Hz occur during normal driving? • Would it be prefferable to have stiff chassis?	• Is it possible to calibrate the speed control to “skip” the frequency where motion sickness occurs (0.2 Hz)?
Tactile sense	• Is cool air beneficial from a motion sickness point of view?	• Does the temperature in the car have any effect on the drivers/passengers degree of motion sickness? • Does fresh air minimize the risk of motion sickness?
Smell	• Can smell trigger nausea?	• Is there any smell that can prevent nausea?
Market offer		• How should a market offer be formulated? • Is it possible to design a market offer that involves “anti car-sickness”? • Should the new solution be included in the car without the customer knowing it is there?

4. Method

The method approach was to gather information from many different kinds of sources and to find solutions with the help of subjective opinions from potential customers aside from other concept development tools. Information was gathered from interviews, literature, research done by scientists and meetings. The information gathering focused mostly on scientific reports, articles, dissertations, interviews and patents. Meetings were held with lecturers and researchers within different fields of knowledge as well as meetings with some of Volvo Cars' employees. Additionally, a meeting with an expert that has studied motion sickness on boats was held.

4.1 Information gathering

The methods that were used to find information is described below; literature study, meetings, interviews and patent search.

Fig. 1. Overview of information gathering techniques.

4.1.1 Literature study

The literature study consisted of a wide search with a basis in the questions from the early stages of the project, and after this; a few areas of the found facts were chosen to be further investigated in a second literature study. Literature was searched in books, at Chalmers library website and search engines. The Chalmers library website consists of a wide range of scientific papers, journals, reports and much more. The website consists of a large variety of databases with different orientations. A database named Summon shows results from all databases at the website. The search can be pinned down by choosing language, type of publication, if it should be a full text, etcetera. During the search, source and a description of interesting literature were written down in a joint document with the purpose to organize found facts.

Phrases used in the beginning of the literature research were: “motion sickness” and “car sickness” and after this other words closer linked to the research questions mentioned in chapter 3 were used. In the second literature study, information about three of the four areas chosen to be further looked into where researched in several different databases and books. These three areas are negative oxygen ions, vibration frequencies and low frequency noise. Information about the fourth area, feedback, was gathered from meetings, interviews and focus group.

4.1.2 Meetings with the purpose to gain knowledge

Meetings have been held during the project with experts, researchers, suppliers to Volvo and personnel at Volvo Cars in order to gain knowledge from their expertise. The information gathering from these meetings have been focused mainly on measured data and possibilities of future measuring techniques, but also to gain from their personal experience, thoughts and ideas on the topic.

There have been meetings with two researchers within the fields of acoustics and seasickness. One lecturer within human machine interaction has been interviewed with the purpose to receive information about design of feedback symbols. In addition to this there have been meetings with 17 of Volvo’s employees and suppliers. Their fields of knowledge are: ergonomics, vibrations, seating comfort, acoustics, infotainment, ventilation, negative oxygen ions, air quality, travelling behavior and reactions to traffic situations, ambulance cars, patent search, wheel suspension and hydraulics.

4.1.3 Interviews

Interviews with users are a good way to get a better understanding for the customers’ problems and their everyday life. In this work, it was decided to use interviews as a way to determine how the effects of motion sickness affect the users’ behavior while driving and how they plan their trips. The interviews were also conducted with the purpose to give a good understanding of the problem and also as a base for ideas. Further, it was used to determine which factors had the biggest influence on the development of their motion sickness, in which vehicles they suffered the most and also if there were any vehicles in which they did not suffer from motion sickness at all.

Three persons were chosen from the criteria that they have suffered from motion sickness now, or at a younger age. The questions were open and simple at first and the interviews were held singly and without using recording devices to make the interviewee feel relaxed. The first questions treated nausea in general and the questions were then narrowed down to be more specific about car sickness. The interviewees were also asked for own thoughts and ideas of possible causes or solutions to motion sickness.

4.1.4 Patent search

A patent search was made with the purpose to find information about the different solutions that already exist in the area of motion sickness and to give inspiration to new solutions. In the patent research, patents and research reports from all over the world have been studied. The search has been made in an open patent database called Espacenet. This database contains over 80 million patents from all over the world (Espacenet Patentsökning, 2012).

Words and phrases used in the patent search were: "motion sickness" AND car, "car sickness", “oxygen ion*” AND health, nausea AND car*, “Mountain sickness” and seasickness. The same search technique was used when doing research in Espacenet and at Chalmers library database. This technique means that different characters and words like: “AND” and “OR” can be used in order to direct the search.

For instance, when using “"motion sickness" AND car” as a search phrase, "motion sickness" has apostrophes to inform the database that it should treat “motion sickness” as one word and not as two. The word “AND” is used to inform the database that results that include both motion sickness and car should be shown. If using “OR” instead, the database will show results for either motion sickness or car. If for example writing: car*, the database will show results for car, cars etcetera. And also for words beginning with “car”, like carbon and cartooning.

4.2 Conceptual design

As a last stage of this project, the information and newfound knowledge were used to develop a number of concepts and ideas for further investigation. During this development of solutions for motion sickness elimination, a brainstorming session and a focus group were held. These methods and how they were used in this project are described here.

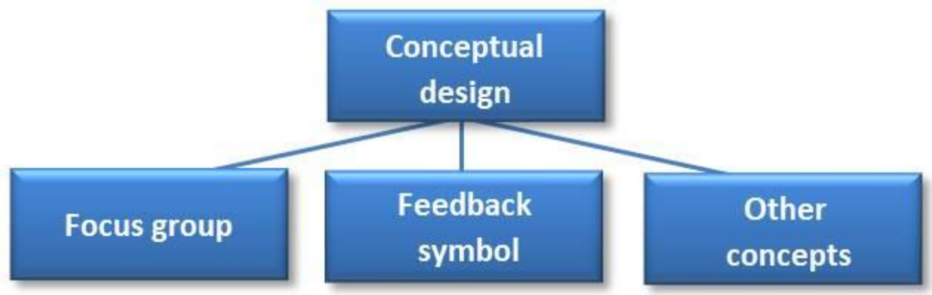

Fig. 2. Overview of elements included in the conceptual design.

4.2.1 Focus group

A focus group is a method that can be used with the purpose to discuss a product that exists or will exist. The recommended number of participants are 5-15 persons and the discussion is led by a neutral moderator that ensures that all participants get to speak their opinion and that the discussion stays on topic. It is favorable that the participants get along and feel comfortable with each other. The purpose with having a focus group is that the group can come up with ideas that could be missed in personal interviews (Johannesson. H, 2004). Below is a description of how a focus group was used in this project.

4.2.1.1 Discussion in focus group of how to design a feedback-symbol

A focus group consisting of five Design Engineers was held parallel to the second literature study in this project. It was used in order to come up with ideas for a feedback symbol and to discuss whether it is possible to have this in a car without worsening the problem with motion sickness. Participants were chosen with the requirement that they have experienced motion sickness because this would make it easier for them to understand the problem and how to solve it. The reason for choosing Design Engineers was that they are used to the method brainstorming and have all participated in a focus group before. The group members were familiar with each other which led to an open discussion where everyone felt comfortable to speak their opinions.

The session started with a discussion around two questions; what do you think causes motion sickness in general? And; what do you do to feel relaxed in a car? The purpose of asking these questions was to make the participants think about scenarios they have experienced. After this, they received a task to come up with ideas of feedback that could inform the driver that motion sickness inducing vibration is occurring. The participants wrote and drew their ideas on post-its for five minutes. The ideas were then reviewed and discussed by the entire group. Afterwards it was discussed whether or not it is possible to use this feedback symbol in a car without worsening motion sickness.

4.2.2 Design of other concepts

At a late stage of the project an idea generation of other concepts took place through a brainstorming session. The concepts were based on the information found in the literature studies, interviews, focus group and meetings. Since the concept design is a small part of the project there were no prototypes or computer models made of the ideas. The ideas were spread over the many different areas, but more focus was concentrated to vibration and visual input since there seemed to be room for many improvements within these fields. The ideas were described in words and a few main concepts were chosen to be described in more detail.

5. Result

This chapter consists of the results found during the project. Facts are taken from reports, books, articles, websites, patents and personal interviews. The result chapter also includes outcomes from focus group and developed concepts. Fig. 3 shows an overview of the areas that have been investigated in this report. The grey circles represent the four areas that were further investigated after the second scope. There is also a reference to which chapter in the report where more information can be found.

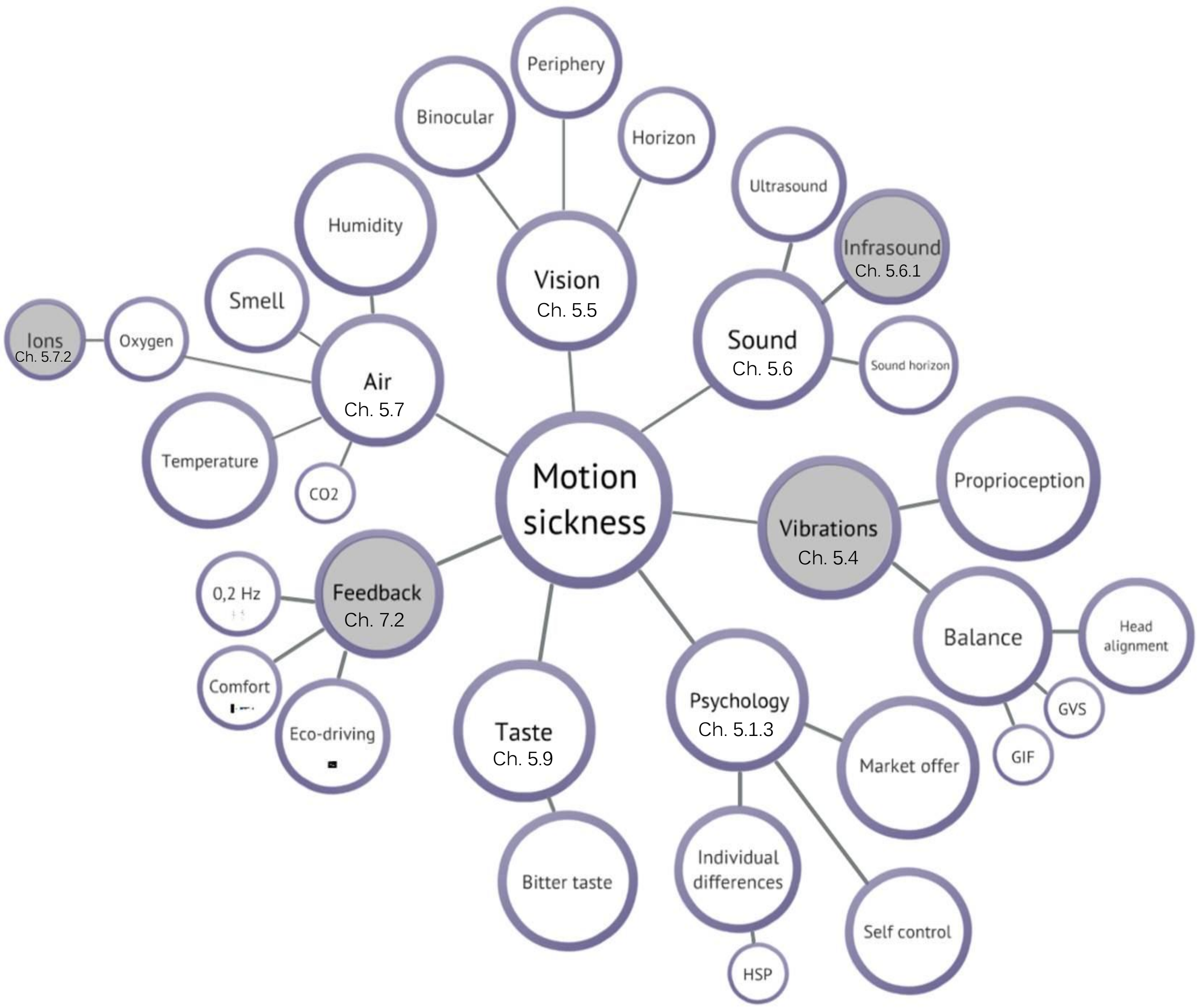

Fig. 3. Overview of some of the areas that have been investigated in this project.

5.1 Why do we become motion sick?

Motion sickness is not an illness; it is a physiological response to a conflict between two or more of the following senses; vision, proprioception[1] and the vestibular system. These conflicts can lead to discomfort, nausea and difficulties concentrating and in worst case scenario, vomiting (Dahlman, 2009). It is unclear if the brain can compare different types of sensory input directly, but it seems to be capable of creating expectations of motion based on earlier experience which is compared with the perceived motion (Bowins, 2010). When we are asleep these comparisons do not happen because the brain does not analyze the inputs, consequently the sensory conflict does not occur and we can accordingly not become motion sick when we are asleep (Dahlman J, 2012). Motion sickness can occur when an unexpected stimulus occurs or when an expected stimulus does not emerge (Dahlman, 2009). One example of this conflict is when reading in a car when it is dark outside; the vestibular system gives then cues of movement, but the visual system does not confirm this movement and these contradictory factors can cause motion sickness (Turner & Griffin, 1999). According to Golding, Bles, Bos, Haynes and Gresty (2003), head alignment also have influence on motion sickness and tests have shown that it is preferable to align the head with GIF[2].

There are primarily two theories that explain why many respond physically with nausea and vomiting to sensory conflicts (Bowins, 2010). These two theories are called the toxin theory and the movement program theory and are described below. Both of them explain, from an evolutionary point of view, the advantage of responding physically to sensory conflict or postural instability. Though it might seem disadvantageous to feel ill under challenging circumstances, it actually has a profitable function for survival. But for the modern day man, these functions have become more of an obstacle than an advantage (Bowins, 2010).

[1] Proprioception is the limbs ability to sense body position (Dahlman, 2009). Proprioception is governed by muscles, tendons, and joints under the skin that works as receptors that responds to physical stimuli (Dictionairy)

[2] GIF stands for Gravito Inertial-Force and is an acceleration resultant arising from acceleration, braking and cornering (Golding, Bles, Bos, Haynes, & Gresty, 2003).

5.1.1 The toxin theory

The first theory, the toxin theory, is based on the idea that the sensory conflicts and postural instability would give us an early sign of intake of neurotoxins[3] (Bowins, 2010). Just like motion sickness is caused by sensory conflicts between eyes and the vestibular system, neurotoxins creates these conflicts. The toxin system works as a backup to our other indicators of poisoning such as taste, smell or vomiting evoked by effects on the stomach's mucosa or stimulation of the chemoreceptors[4] after absorption. Still, there are some things that contradict this theory as mentioned below.

Primarily, it might seem redundant with an additional warning system to toxins besides the many other protecting functions in our body mentioned above. In supplement to this, our liver has a detoxifying effect and gets rid of most toxins that get past the other warning systems (Bowins, 2010). To have a warning system that alerts us of toxins that has already crossed the blood-brain barrier also have a very small biological advantage since the toxins that has reached the brain cannot be removed by vomiting (Bowins, 2010). The only function in this stage of intoxication is that the unpleasant effects might prevent us from ingesting more of the food or beverages that caused the poisoning. In addition, not all motion sickness leads to vomiting which opposes the explanation that the key purpose of motion sickness would be to remove toxins. Another fact that contradicts to this theory is that toddlers, whose brains are rapidly developing, should be highly sensitive to toxins but on the contrary don't experience motion sickness at all (Bowins, 2010).

5.1.2 The movement program theory

The second theory, the movement program theory, is based on the idea that a negative and uncomfortable experience of motion other than expected would discourage the development of movement programs adapted to situations where these vestibular conflicts occurs (Bowins, 2010). The explanation to why our body would like to achieve this is due to the fact that motions that are significantly different than the expected or that produces imbalance, would have caused injuries or signaled vulnerability to predators and thus reduced evolutionary fitness. In other

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[3] Toxic substances that affect the brains nervous tissue and block signals from one nerve-cell to another (Nationalencyklopedin)

[4] Chemoreceptor is a sensory nerve cell or sense organ, as of smell or taste that responds to chemical stimuli (Dictionairy).

words, motions beyond our control often increase the risk of injuries (for example rolling down a hill). There is however a few number of animal-species who does not suffer from motion sickness. Some of them have a well-developed protection towards injuries caused by unstable motion and some uses the unexpected motion to their advantage, like the rabbit that has evolved motion patterns different from the expected to deceive predators (Bowins, 2010).

The phenomenon is explained as a negative reinforcement model, a sort of natural obedience training, to make us stop undesirable behavior and elude the probability of injury. The obnoxious sensation of motion sickness is meant to make us stop the motion to reduce the feeling, and the vomiting is meant to force us to stop what we are doing since vomiting is inconsistent with substantial movement. The effects of the negative experience can lead to early avoidance, reduction of movement and removal of oneself from the offending circumstances (Bowins, 2010).

This theory has, just like the former, some contradictory arguments against its probability. First of all, a positive reward for a correct executed task is much more efficient than a punishment. For example, young children obtain satisfaction when being able to keep balance and walk towards a desired toy. This might imply that the negative reinforcement system is redundant. A second argument against the theory is that toddlers would benefit from this correcting function more since the development of the perceptual-motor programs is very active in the early years where motion sickness, on the contrary, is nonexistent (Bowins, 2010).

5.1.3 Individual susceptibility to motion sickness

Susceptibility to motion sickness varies between different persons and also within an individual depending on the occasion (Griffin, 1990 p.286). Individual susceptibility depends on a variety of reasons such as adaptation ability and expectations due to earlier experiences (Dahlman, 2009). It is primarily kids in the age 4-10 years who suffer the most from motion sickness (Setness & Van Beusekom, 2004). Some outgrow the symptoms while others have lifelong problems in greater or lesser extent. One reason to why adults often not suffer as much from motion sickness as children might be that they have been able to adapt to the stimuli or that they avoid situations or stimuli that they have negative experiences from (Griffin, 1990 p.287). The literature study has also shown that differences in age (Natan, 2004) and personality (Toikkanen, 2006) also play a role in people's susceptibility to motion sickness.

The American researcher Elaine Aron has found a personality trait within one of five humans and also within many different animal species which has been named HSP, or Highly Sensitive Person (Aron, 2012). It is believed to be an inherent personality type and is as common among men as women. These individuals are stronger affected by sensory impressions (sound, smell, vision and social encounters) and analyzes these deeper which requires more brain activity and can make these individuals exhausted from busy environments. These persons also have a higher probability to develop symptoms of stress or depression from these stimuli (Lagerblad, 2012). HS-persons doesn't have a better sense of smell, better hearing or better vision, but have a lower threshold for these inputs and through MRI[5] it has been proven that their nervous system reacts much stronger to these external stimuli than that of the average man. These individuals are also more sensitive to hunger and thirst and their ability to concentrate and mood state can be easily affected negatively by this (Lagerblad, 2012).

5.1.4 Vomiting

One of the many consequences of motion sickness is vomiting and this chapter describes the different inputs that cause vomiting.

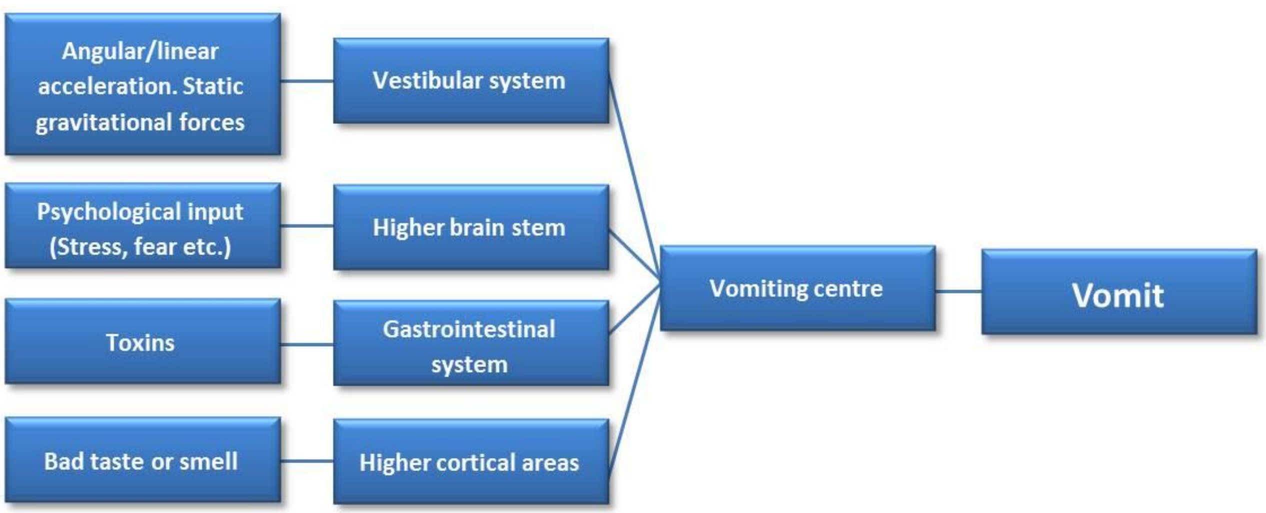

Fig. 4. The connection between different kinds of input that causes vomiting.

[5] MRI means magnetic resonance imaging and is used to visualize internal structures of the body (Dictionairy)

One of the many symptoms of motion sickness is vomiting and this consequence is far more common in simulators where the boundaries can be pushed with heavy vibrations, drastic turns and also very disturbing visual impressions with the help of optokinetic drums (see fig.5) (Dahlman, J. 2012). The causes of vomiting are input from the vestibular apparatus, higher brain stem[6], cortex[7], gastrointestinal system[8] or viscera[9] (Marin, Ibañez, & Arribas, 1990). The input derives from either chemical or mechanical stimuli on the body. In the case of motion, the symptom of vomiting primarily refers to stimuli on the vestibular apparatus, but vomiting in cars can also be triggered by input from the cerebral cortex[10] which acts on stimulation of the senses smell, taste and vision. The psychological part of motion sickness could also trigger vomiting on its own since the higher brain stem and cortical structures can produce signal input to the vomiting center when stimulated psychologically.

[6] The middle part of the brain (Nationalencyklopedin)

[7] The cortex is a thin layer of grey brain tissue, containing an extremely large number of nerve cells and covers the surfaces of the two brain halves (The free dictionary).

[8] The system that makes food absorbable to the body (The free dictionary)

[9] Soft internal organs of the body (Dictionairy), in this case: heart and testicles

[10] The cerebral cortex is mainly responsible for higher brain functions including voluntary muscle activity and learning, language, and memory. (Dictionairy).

5.2 How to test motion sickness

Motion sickness is often tested with the help of motion simulators or optokinetic drums (see fig.5).

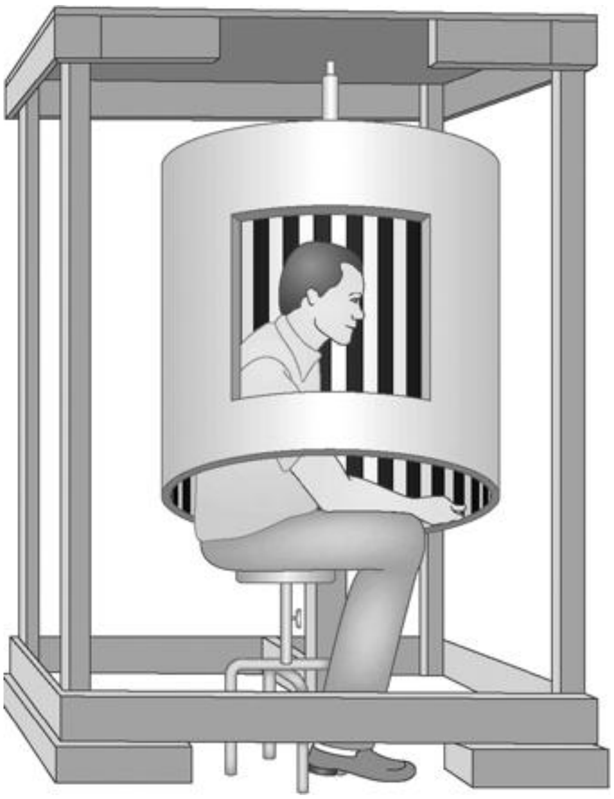

Fig. 5. An image of an optokinetic drum that is used in experiments for testing motion sickness. A test-person sits inside a large, rotating cylinder with a striped pattern that cause visual input of movement. Picture received from (Max E. Levine, 2006).

It can be easier to evaluate motion sickness in a laboratory environment because highly provocative stimulation can be used. It is harder to identify motion sickness during operational conditions because the activity levels, how the vehicle moves and the environmental conditions are not as controlled as in a laboratory (Lackner & DiZio, 2006). Conducting tests in laboratory environment also makes it easier to compare data from different test runs and the values become more accurate (Tesfay).

There are difficulties of reaching good validity in general when testing motion sickness because of the test person's awareness that he/she will participate in an experiment where motion sickness may occur. This increased awareness often leads to triggered or enhanced symptoms that would not emerge in a normal situation. Other difficulties with simulator tests are that movements have to be decreased relative to the reality in order to prevent the test person from experiencing the movements as being exaggerated. The horizon on the screen is also blurry in a visual simulator, and is therefore hard for the eyes to focus on (Genell, 2012). This factor makes simulators trigger nausea more easily due to the fact that being able to focus on a horizon is beneficial from a motion sickness perspective (Griffin M, 1990. p.325). Additionally, the display has a slight delay that cause disturbance between senses. This delay does not occur in a real car and is therefore another reason to why simulators differ from reality (Dahlman J. 2012).

5.3 The vestibular system

The vestibular system is affected by vertical and horizontal vibrations and forces of acceleration. This is explained below.

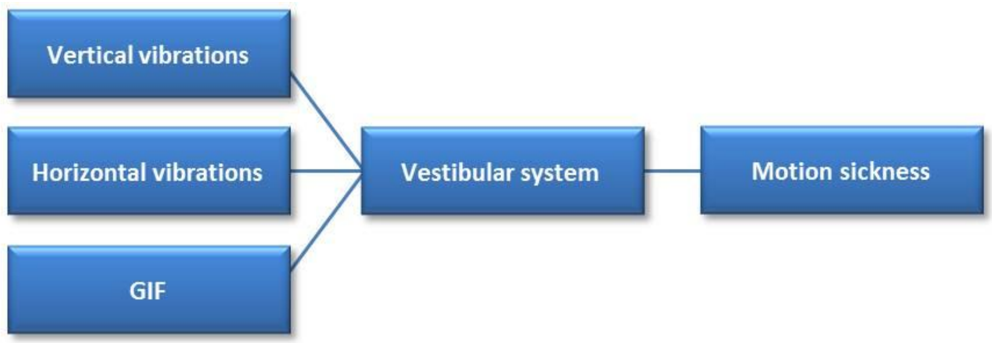

Fig. 6. Overview of inputs to the vestibular system that results in motion sickness.

The vestibular system is what helps us keep our balance. It registers changes in position caused by motion and controls the position of the head through regulation of muscle tension which helps us keep our posture. The vestibular system consists of semicircular canals and otolith organs (Dahlman J, 2009). Small calcium carbonate crystals on a gelatine material constitute the otolith organ that helps us detect linear acceleration and the position of the head (Nationalencyklopedin). This tells us that we are moving forward. It is thought to be their inability to conclude some motions that is the reason for some disorientation and motion sickness. The otoliths are considered to be responsible for the eyes moving in the opposite direction when the head moves in a roll motion. This is called ocular counter-rolling (Griffin,

1990. p.278). The part that detects angular acceleration is hair cells, called cilia, attached to the inside walls of the semicircular canals. The indication of angular acceleration tells us that our head is moving (Dahlman J. 2009).

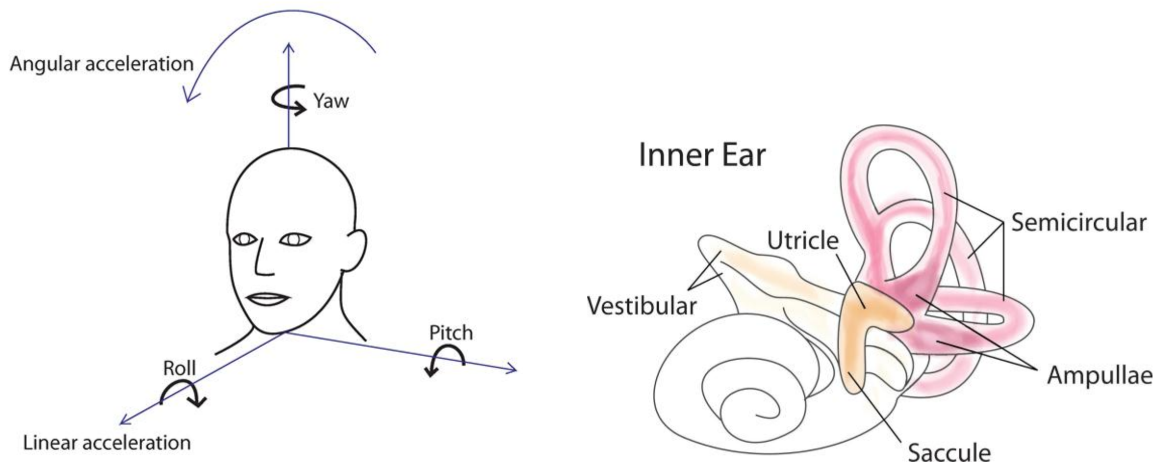

Fig. 7. Description of roll, pitch and yaw rotation, angular and linear acceleration and to the right a description of the inner ear. Inspiration for drawings were found at Evolve media.

5.3.1 GVS - Galvanic Vestibular Stimulation

It has been found that the vestibular organ and our balance can be controlled with the help of a headset called GVS (Galvanic Vestibular Stimulation). It disturbs the nerves inside the ears with electric impulses. A report by E. Schneider describes a test where GVS was used. The purpose of the test was to isolate the otolith activation and stop the rotational effects. By self-adjusting the amplitude and phase of GVS, subjects were able to minimize their sensation of rotation and to generate the perception of linear translation (Schneider. E, 2009).

5.3.2 GIF - Gravito Inertial-Force

In a car, the driver tends to not get as motion sick as the passengers. One reason for this might be that the driver can anticipate the vehicles direction and therefore aligns his head with GIF (Gravito Inertial-Force). This is an acceleration resultant arising from acceleration, braking and cornering.

A test that evaluate whether compensatory alignment or misalignment with GIF would reduce motion sickness when the test person is active or passive to the compensatory alignment has been found. When the test person is passive, the simulator controls the alignment and when the test person is active, it is the test person that controls the alignment. The test also investigated the effect of the head tilt and the importance of active control in motion sickness. The experiment showed that motion sickness is reduced when the test person is aligned with GIF and if he/she has control of the alignment (Golding, 2003). Researcher M.J. Griffin on the other hand recommends design that creates support for the head to reduce movements of the head relative to GIF which creates a passive role for the individual (Griffin M, 1990, p.322).

An important factor in making compensatory GIF-alignment successful is to avoid sensory delays. An example of an experiment on GIF-alignment that created these delays is the X2000 trains that, when they were new, caused many cases of motion sickness among their passengers (Persson, 2011). They had a sensor connected to an automatic tilting function that made the train tilt in the curves to counteract the acceleration force. The problem with this was that the sensor was placed in a way that caused sensory conflicts within the passengers because the train tilted too soon or too late in relation to what they expected.

5.4 Frequencies

This chapter focuses on how vibrations affect motion sickness, how vibrations feel and individual susceptibility to vibrations. There has been much research made on the importance of vibration frequencies on the development of motion sickness (Dahlman J, 2009). The discomfort of vibrations depends on many different things: the magnitude, the frequency, the direction, and the duration of the vibration and where the vibration has contact with the body (Griffin, 1990. p.122). Vibration is an oscillatory movement and the oscillations extent determines the magnitude. The repetition rate of the oscillating cycles determines the frequency (Griffin, 1990. p.3). Low frequencies are approximately below 3 Hz and high frequencies are higher than 3 Hz (Griffin, 1990).

A cars eigenfrequency[11] in vertical direction is no lower than 1.1 Hz and longitudinally[12] no lower than 6 Hz (Krüger, 2012). Though, motions of frequencies lower than 1 Hz can occur and is in such cases caused by the profile of the road surface (vertical vibration), turns (lateral

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[11] The resonance frequency of a system (Collins beta)
[12] In the direction of the length; lengthwise (Dictionairy)

acceleration) and braking (fore-and-aft[13] motions). All three of these are affected by vehicle speed and, in differing ways, driver behavior (Griffin M. J, 2004). Low frequency oscillations are usually a consequence of road surface and are not sufficient to explain the incidence of motion sickness (Griffin, 1990. p.324).

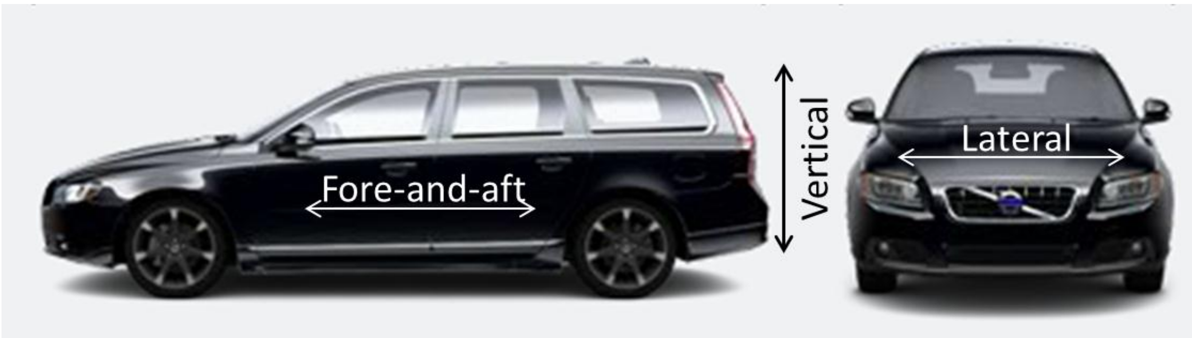

Fig. 8. Directions of motion that can occur in a car. Horizontal direction, as mentioned in the text, comprise both lateral and for-and aft motions but also other motions in diagonal horizontal direction. Picture found at (Volvo).

5.4.1 How do vibrations feel?

The sensation of vibrations with a frequency of 1-2 Hz can be compared to a “swinging” motion or a side-to-side motion experienced in a train (Griffin M.J, 1990. p.29), 3-8 Hz with “tugs” and 8-20 Hz is perceived like “shakes” (Krüger, 2012). Vibrations in vertical directions are most uncomfortable while in the frequency of 5 Hz while vibrations in horizontal directions are most uncomfortable at 1-3 Hz. Frequencies in vertical direction are affected by the vehicle and “fore-and-aft” motions in horizontal direction and lateral frequencies are mostly caused by the driver. Some human responses to these motions may be adjusted by the design of the vehicle (Griffin M. J, 2004). Due to difference in firmness of the human body parts, a difference in eigenfrequencies follows. The head’s eigenfrequency is approximately 25 Hz, the stomach’s 4-8 Hz, and the eyeball’s 20-25 Hz and so on (Fredriksson, 2012). There is a risk that when the eyeball’s eigenfrequency occurs, a disturbance in the vision due to the vibration of the eyes might provoke a feeling of motion sickness (Genell, 2012). Longitudinally, the body is most sensitive in the range 4-8 Hz and transversely, the range is 1-2 Hz (Burt, 1996).

[13] Parallel with the length of a structure; running lengthwise (Dictionairy)

5.4.2 Individual sensitivity to vibrations

The human body responds differently to vibration frequencies depending on which body part and in which direction the force acts. How the frequencies affect humans depends on the proportions of a person's body and the type of frequency that affect the person. It has been shown that big persons are less sensitive to “fore-and-aft” vibration frequencies that are less than 6.3 Hz but they are more sensitive to high frequencies in vertical directions (Griffin M, 1990. p. 92). Tests also show that there are no differences in age when it comes to sensitivity to vibrations (Griffin M, 1990. p. 93).

5.4.3 Low frequencies (< 4 Hz)

The most common conclusion is that in vertical direction, frequencies between 0.16-2.0 Hz are the worst from a motion sickness point of view (Dahlman J, 2009). The frequency range of 0.1-0.5 Hz may remind people of the vertical oscillations of a ship and is known to induce motion sickness (Griffin M, 1990. p.29). This frequency is often used when testing motion sickness because it is an effective way to trigger nausea.

Low vibration frequencies in vertical direction in cars in the 0.1-0.5 Hz range are however usually not of a sufficiently high intensity to cause motion sickness (Griffin M, 1990, p.319). Frequencies in this area are also quite independent on construction of the car and do not vary widely between soft and stiff suspension. These differences are greater in the area of 1-2 Hz (Griffin M, 1990, p.319). Low-frequency motions between 0.1-0.5 Hz in horizontal directions are on the other hand thought to be prime causes of motion sickness in road vehicles (Griffin M. J, 2004, p.319).

The dynamics of a seat often have little influence at frequencies below 1 or 2 Hz but at approximately 4 Hz they amplify vertical vibration to an unacceptable magnitude (Griffin M, 1990. p.31). Frequencies below 1 Hz in horizontal directions may be resisted by the muscles but when frequencies reaches 1-3 Hz it is hard for the upper body to remain posture but a backrest can help stabilize horizontal vibrations in the upper body and resist the effects of motion (Griffin M, 1990. p.31).

Orientation of the otoliths when in an upright position makes them more sensitive to horizontal acceleration (Griffin M, 1990, p.307). A conclusion made by researcher M.J. Griffin is that humans are more sensitive to low frequency horizontal oscillation than low frequency vertical oscillation in a sitting position. Tests have also shown that the posture have big influence on transmissibility of vibration to the body. Fig. 9 shows that if the posture is slouched and the frequency is high, the transmissibility is low and when posture is erect and frequency is high, the transmissibility becomes higher than previous example. Posture does not have big influence on the transmissibility when frequencies are low.

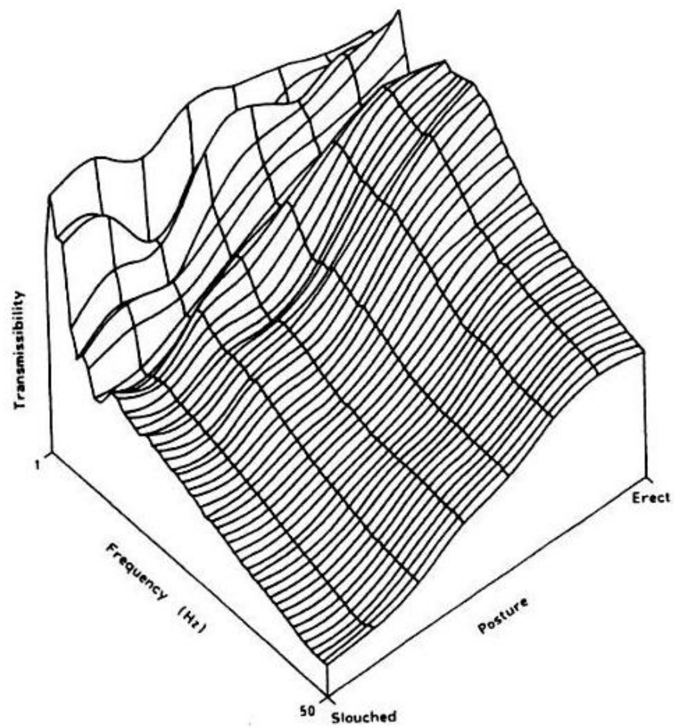

Fig. 9. The picture show the effect of sitting posture on the transmission of vertical vibration from the seat to the head. Source (Griffin M. , 1990. 345).

5.4.4 High frequencies (> 4 Hz)

Motion sickness is rarely a problem at high frequencies. But at these frequencies other problems emerge, such as a sensation of discomfort. At high frequencies in “fore-and-aft” directions, the seat is often the main source of vibrations multiplying in the body (Griffin M, 1990. p.31).

5.4.5 Vibrations in different directions

Most of the studies of vibrations have been of single frequency; vertical single-axis vibration and other single-axis vibrations. But in reality, people are exposed to multiple frequencies and vibrations in different axes at the same time (Griffin M, 1990. p.78). There are conjectures that motion in many different frequencies and directions might increase the risk of motion sickness (Griffin M. 1990). As mentioned earlier, a few tests have been made that contain vibrations in different directions. Because this occurs in a car, it might seem like a good idea to do more tests that comprise these different directions. However, it can be difficult to perform such a test because the vibrations may be perceived different by the test person due to distraction of the other vibrations (Griffin M, 1990).

5.4.6 Combination of vibration and noise

Combinations of vibration and noise can affect the perception of vibration (Griffin M, 1990. p.123). This has for example been shown in tests performed in flight cabins. If noise is increased, test persons tend to perceive the vibration as less disturbing but if noise is decreased, test persons often register the vibrations more (Genell, 2012).

5.5 The visual system

The visual system is an essential part of the phenomenon of motion sickness since it helps us to verify what other receptor organs tell us to expect (Dahlman J. 2009). Hence, an optical illusion of movement while standing still, or an illusion of non-movement while moving will create a conflict between signals to the brain from the eyes and from other receptor organs, such as the vestibular system. A conflict can also be created through an optical illusion of moving in an opposite direction than the actual.

5.5.1 Vision in a car

There are different opinions of what effects a restricted visual field has on motion sickness. Some researchers claim that it is most beneficial not to see what happens in the periphery while some assert that it is better to see as much as possible regardless if it is only in the periphery or not. In this report, a conjecture is made that it is more beneficial to see as much as possible of things outside the car with a focus on the horizon and preferably a forward view. This conjecture is based on a test made by Turner and Griffin seen in fig. 10.

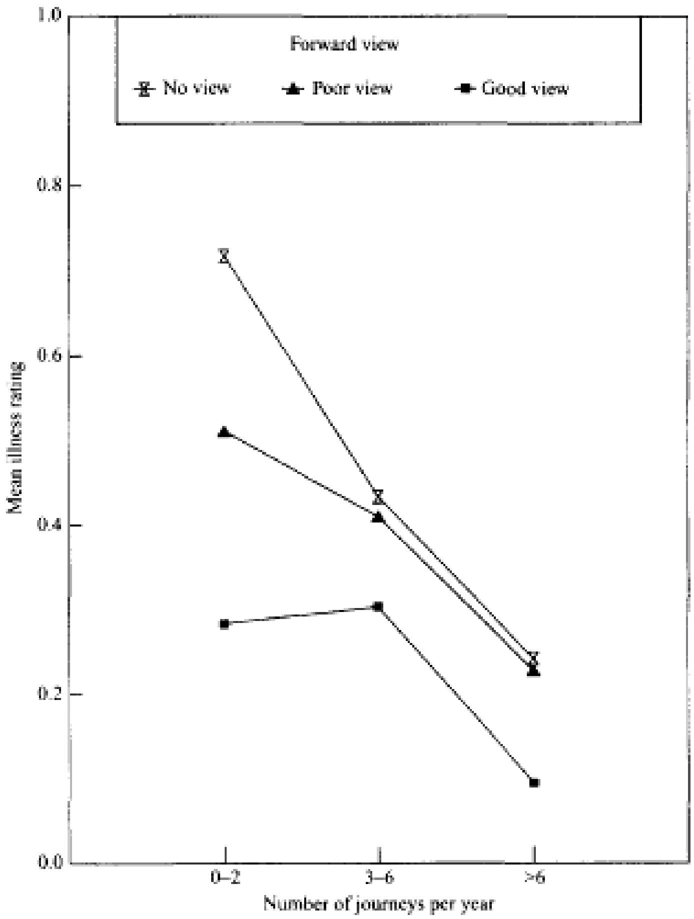

Fig. 10. Mean illness rating as a function of forward visibility and travel regularity for 3256 coach passengers. Picture source: (Turner & Griffin, 1999).

In a car, the driver and front seat passenger have relatively unrestricted view over the road and good side view. The backseat passengers on the other hand, have limited view of what is outside the car. There are seats and headrests blocking the frontal sight and Volvo's modern cars have a high beltline that has been raised considerably in just a few decades. This is because of design constraints as a result of what is perceived as fashionable in car design, but also because the A- and B-pillars has thickened to protect the passengers if a collision would occur (Johansson). The A-, B- and C-pillars narrow the vision and it seems that it is not only their width and depth but also their angle that affects the visual scene. This limited field of view results in an increased risk of motion sickness for the back seat passengers since they cannot see the difference in altitude and turns of the road. According to survey data and measurements made by Mark Turner and Michael J Griffin, the results show that improved forward visibility can reduce motion sickness, especially for people who do not travel often or travel for the first time. Movement in the whole or parts of the visual scene can be enough to cause motion sickness and motion of the head or body is not required for motion sickness to occur (Turner & Griffin, 1999).

5.6 Hearing

The fact that our health can be affected by sound and noise is known by most people and we are from a very young age taught to protect our ears against high noises. What some might not know is that we also can be highly affected by noise we cannot hear, such as low and high frequency sound, or infrasound and ultrasound.

The most common opinion among researchers is that the audible range for humans lies between 20 and 20 000 Hz for adults and down to 16 Hz for children (Nationalencyklopedin). Though, the lowest recorded audible frequency level is at as low as 1.5 Hz in headphones. This is because of the fact that the human range for audible sound frequencies depends much on the sound pressure level; the higher pressure, the lower audible frequencies. For example: the threshold for 4 Hz lies on 107 dB and the threshold for 200 Hz lies on 14 dB (Leventhall, 2007). The threshold for audible sound shifts with age and hearing damage and it is often high frequencies that become inaudible with age. But even though they are inaudible, they can still be perceptual.

The frequencies over 20 000 Hz are called ultrasound and are often used within the medical care and in industries for cleaning tools and material testing (Arbetsmiljöverket). The frequencies below 20 Hz are called infrasound and include wavelengths from 17 meters and upwards (Nationalencyklopedin). These can both occur in cars and affect us in one way or another.

5.6.1 Low frequency sound

Facts have been found that infrasound can have negative influence on humans. These frequencies have been measured in a Holden station wagon at the passenger position where 112 dB (around 6 Hz) occurred when driving in 110 km/h (Broner, 1978).

Low frequency sound can produce physiological and psychological effects in form of fatigue, pressure in the ears, headache, nausea, concentration difficulties, disorientation, seasickness, digestive disorders, cough, vision problems and dizziness (Burt, 1996) and can also affect learning and memory negatively (Hua Yuana, 2009).

Fig. 11. Overview of correlation between low frequency sound and motion sickness.

The low frequency sound affects the vestibular system due to the sound waves that allows the hair cells in the ears to sway. This tells our brain that we are moving even though we are standing still. Excitability of the vestibulum seems to be accelerated by low frequency noise and this happens even if the person concerned is not affected in any other way (Schust, 2004). Exposure to infrasound can also create deflections in EEG[14] patterns and alterations of systolic and diastolic blood pressure and heart rate (Schust, 2004). Another effect that can occur is that the body starts to vibrate from the sound waves. This however requires a very high sound pressure (~130 dB) and that the tissue contains gas (Landström). Affected body parts are lungs, sinuses, gas-filled intestines or stomach and tympanum (Landström). The early discovering of infrasound is made by the hearing which is why deaf people are not affected by it before the intensity where the body starts to vibrate (Nilsson. M.E, 2011). Through scientific experiments on humans it has been found that the frequency of 7 Hz produces the strongest feeling of discomfort and nausea (Schust, 2004).

Values in fig. 12 show sound pressure values for each frequency measured by the Swedish work environment authority, at which effect on humans normally can be registered. Hence must not

[14] Electroencephalogram is a graphic record of the electrical activity of the brain as recorded by an electroencephalograph (Dictionairy)

sound pressure levels over-exceed the given sound pressure level in places where people spend longer periods of time.

Center frequency 1/3-octave band [Hz]	Sound pressure level [dB]
2	130
2.5	126
3.15	122
4	118
5	114
6.3	110
8	106
10	102
12.5	98
16	94
20	90

Fig. 12. Limiting values for low frequency sound defined by the Swedish work environment authority. Information found at Arbetsmiljöverket.

These values lie 5-10 dB above the perception threshold and in an environment where you promote good health, these lower values should not be exceeded either. Hearing is very individual and even lower sound pressure could lead to discomfort within sensitive individuals with hearing damage (such as tinnitus) or sensitive hearing because of other causes. The differences between perceived noise and uncomfortable noise have also been shown to be very small within the low frequency area. In the audible range a difference of 10 dB is perceived as a doubling of sound intensity in contrast to the low frequency area where duplication is perceived already at a 5 dB difference. The low frequency noise has also been established to be harder to adapt to and tolerate than for higher frequency noise in the audible range (Landström).

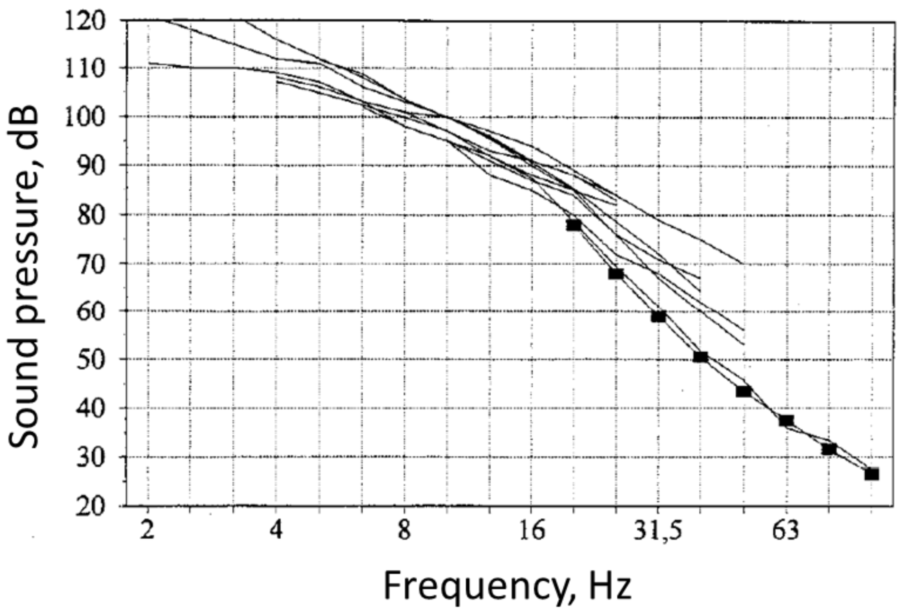

Fig. 13. Summary of experiments on perceivable threshold limits for low frequency sound, based on experiments made by M.L.S. Vercammen, R.E. Walford and T. Watanabe.

Also this chart of hearing thresholds summarized by the Danish environmental authority also suggests that Swedish limiting values is set by the higher threshold and that there are individuals that are affected from infrasound from 10 dB under the set values, which is equal to a quadrupling of the perceived sound intensity (due to the fact that a raise of 5 dB within the low frequency area is perceived as a duplication of sound intensity) (Landström). The Danish environmental authority have developed a stricter guideline of limit values for infrasound described below, based on the criteria that it should not affect 97% of the population (Lavfrekvent støj, infralyd og vibrationer i egstremt miljø, 1997). This however, is for longer sound exposure under an eight hour work day which is probably not as common in a car. It also lacks a division between different frequency bands and generalizes all below 20 Hz. It does not make any distinction between the less susceptibility of the higher sound frequencies and the higher audible threshold of the lower frequencies.

Area		G-weighed sound pressure level below 20Hz
Living area	Evening/night (18.00-07.00)	85 dB
	Daytime (07.00-18.00)	85 dB
Work place, classrooms etc.		85 dB
Other areas in business		90 dB

Fig. 14. Limiting values for low frequency sound below 20 Hz defined by the Danish environmental authority, based on the 97th percentile. (Lavfrekvent støj, infralyd og vibrationer i egstremt miljø, 1997).

There is a small group of the population (2.5%) that suffers from sound sensitivity (Leventhall H. 2004), also called hyperacusis (Buller, höga ljudnivåer och buller inomhus, 2008). In the age 50-59 years it is as high as 10% in Europe (Leventhall H. 2004). The sensitivity has been recorded as low as 15 dB below the ISO 226 threshold, but is in general closer to 10-12 dB under (Leventhall H, 2004).

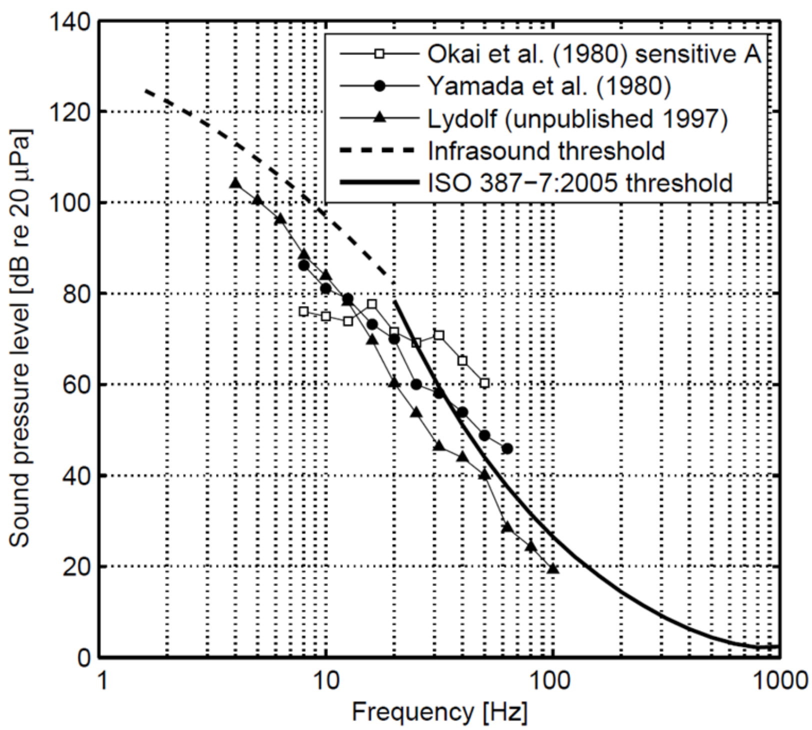

Fig. 15. Compilation of experiments on hearing threshold in the low frequency range containing comparison of individuals with highly sensitive hearing and normal hearing threshold. Picture found at (Pedersen, 2008).

The researcher within acoustics, H.G. Leventhall recommends a limit value of 15-20 dB below the average threshold as a "rule of thumb" to cover more sensitive individuals' level of perception (Leventhall H, 2004), although he also mentions that this might be a bit generous and must be seen as an approximate value to give an indication of the problem's extent. If you were to recalculate the limiting values to a more suitable level for individuals with sensitive hearing accordingly to Leventhall's recommendations, it would be closer to the values shown in the table in fig. 16. These values are based on the assumption that the values from the Swedish work environment authority are approximately the hearing threshold for the average man.

Center frequency [Hz]	Recalculated sound pressure limit [dB]
2	110-115
2.5	106-111
3.15	102-107
4	98-103
5	94-99
6.3	90-95
8	86-91
10	82-87
12.5	78-83
16	74-79
20	70-75

Fig. 16. Recalculated limit values for low frequency sound according to H.G Leventhall's recommendations of a sound intensity 15-20 dB below the hearing threshold.

5.6.1.1 Low frequency sound in cars

Things that might increase the level of infrasound in cars are: road surface, vehicle speed, size of the auto body, roof racks and open windows or sun roof (Haddad, 1985). It can also originate from engine and/or transmission vibration, running wheel vibrations and aerodynamically generated sounds (Onusic, 2005).

As mentioned in chapter 6.6.1, there have been recordings of infrasound in vehicles with the purpose to investigate if there are elevated levels that can cause health effects. A research made by DaimlerChrysler in 2005 also shows that higher level of low frequency noise occurs when solar roof or windows are opened (Onusic, 2005), as shown in the diagram in fig. 17.

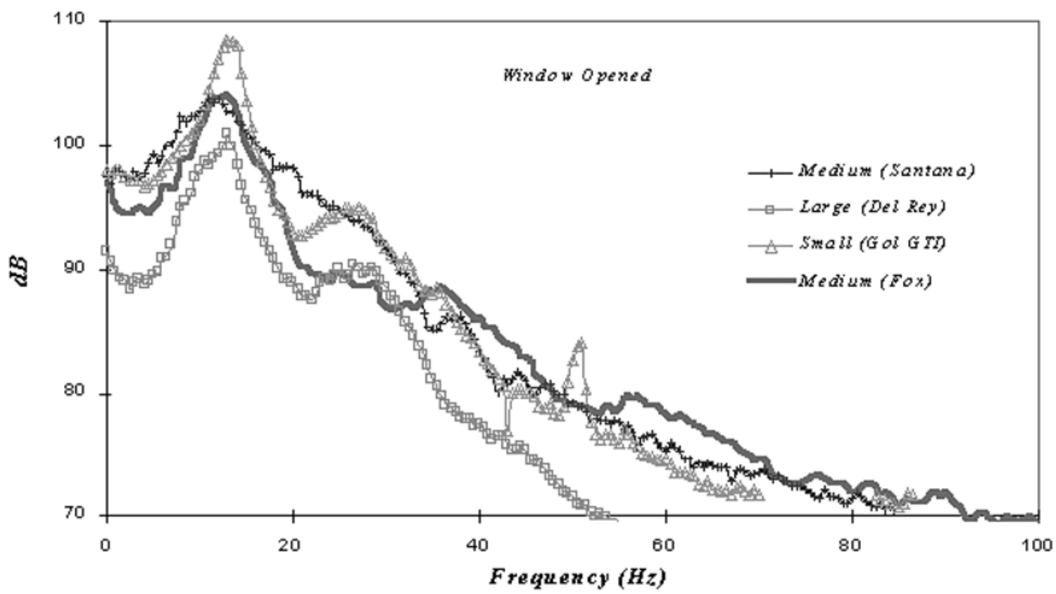

Fig. 17. Levels of low frequency sound in different passenger cars at a speed of 120 km/h with one window opened. Picture found at (Onusic, 2005).

At the same speed, but with all windows closed, there is a significant decrease in low frequency sound intensity. Still, there are peaks in the low frequency area that rise well above 80 dB and that, accordingly to the recalculated limit values, could produce discomfort for sensitive individuals.

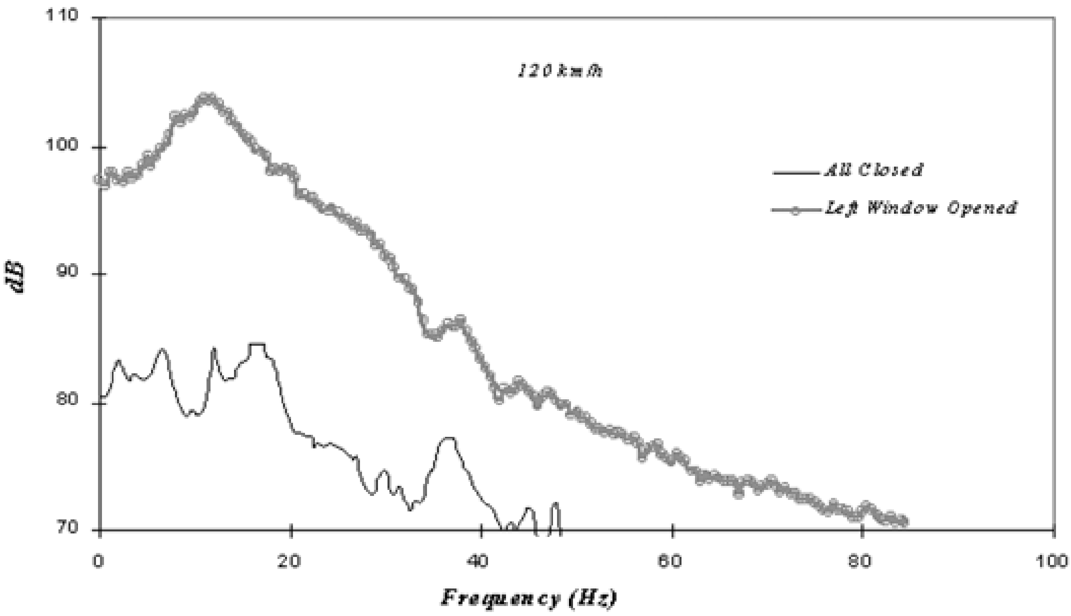

Fig. 18. Levels of low frequency noise in a passenger car of medium size. The diagram shows values for two tests at a speed of 120 km/h where one was with all windows closed and the other one with left window opened. Picture found at (Onusic, 2005).

Another thing that can cause low frequency sound is “air pumping” (see fig. 19) that originates from air compressing in front of the tires when driving on a very smooth surface. The audible part of this phenomenon can be heard as a hissing noise (Bergiers, 2009). A way to counteract this is to add a fine texture to the road surface of grains smaller than one centimeter in horizontal direction or making the underlay porous (Bergiers, 2009).

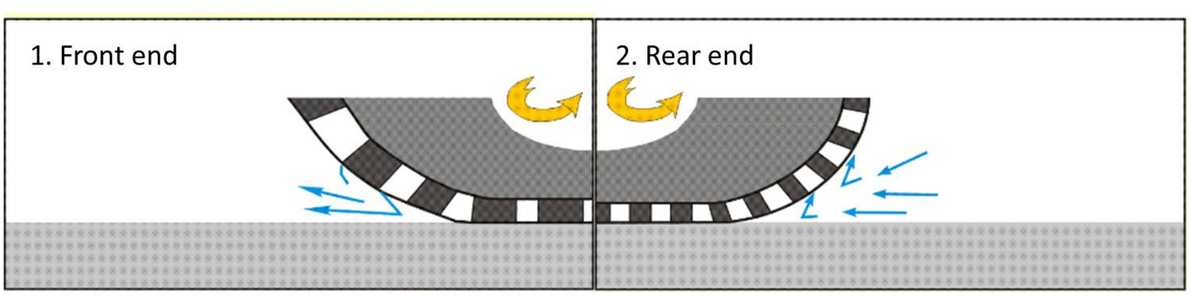

Fig. 19. How air pumping is generated. As seen in part one, the air is compressed in front of the tire and then escapes with a hissing noise in the rear end of the tire (part two). Picture found at (Bergiers, 2009).

5.6.2 High frequency sound

High frequency sound, or ultrasound as it is also called, can cause a feeling of pressure over the ears in combination with a sensation of heat or burning in the ear's inner parts with nausea and dizziness as a result (Landström, Ultraljud, 1999). It has also been related to other subjective sensations in the form of headache and fatigue. These symptoms occur because the ultrasound overstimulates hair cells and sensory receptors in the auditory organ. It has been shown through tests on workplaces and in laboratories that the frequency range between 22-28 kHz produces the strongest feeling of discomfort and pain (Landström, Ultraljud, 1999). Though these symptoms are rare amongst humans below 90 dB and do not occur normally before 100 dB at the frequency of 20 kHz.

Ultrasound can effectively be stopped by relatively simple absorbents or ear mufflers since the short sound waves have a very restricted translation potential. Many researches have also shown that ultrasound is easier to endure if it is masked by another sound (Landström, Ultraljud, 1999). Ultrasound has however no proven effects of hearing loss other than temporary when exposed to high sound pressure levels over 100 dB near the audible threshold around 20 kHz. Even so, if the ultrasound is distributed directly through the body it can heat up the tissue and cause tissue damage at intense exposure (Landström, Ultraljud, 1999).

It seems to be a relatively poorly researched area whether a car can contain ultrasound or not if compared to the research made on infrasound. But according to a manufacturer of technical measuring instruments, called *Omitec*, these high frequencies can occur from mechanical, electrical, fuel and other high-pressure air, oil and water systems if there is a pressurized leakage, friction or electrical anomalies (Omitec). Since ultrasound, according to Omnitec, is something that should not occur in a normal functioning car it is something that will not be further looked into in this project.

5.7 Smell and respiratory system

The experience of scents, temperature and air humidity is quite individual and it is hard to set a standard for good smells or bad smells and to put a value on temperature and humidity that suits everyone. How you experience temperature depends much on your own body temperature, wind and physical state (e.g. how tired you are) but is also linked to the air humidity (Andersson, 2012). The experience of smell is on the other hand very psychological and depends much on former experiences and memories of the scents. The evaluation and categorization of different smells into pleasant and unpleasant smells does not work in the same way with children under five years of age as it does with older children and adults (Allt om vetenskap, 2006). Some smells are analyzed intuitive by our brain and is part of a defense mechanism, like the smell of smoke or rotten food. Other perceptions of scents are influenced by culture and people around us. This might explain why young children do not, for example, categorize the smell of excrement as unpleasant until after five years age.

Since man started walking on two feet the ability to perceive odor signals has regressed since it became less important, and hearing and vision took over instead. The smell receptors occupy only a small percentage of the brain, and less space than the receptors for vision and hearing. Despite this, we are much stronger influenced emotionally by impressions of smell than of visual and auditory impressions. Scents can even create anxiety and hallucinations (Allt om vetenskap, 2006).

5.7.1 Individual susceptibility to smells

It has also been found that shy and introverted individuals have a more sensitive sense of smell. This is believed to be caused by a more alert warning system; they are more aware of things that can be perceived as dangerous and also feel more vulnerable (Allt om vetenskap, 2006). The experience and influence of scents also depends on how sensitive you are to smells in general; there is for example an increased sensitivity towards smells within asthmatics and allergic individuals. There is also a part of the population (six percent in Sweden) that is so called fragrance hypersensitive which means that they are sensitive toward smells without an underlying allergy or asthma (Hallingberg, 2008). These individuals have an inherent reduced threshold for the nerve receptors in the mucosa which causes them to experience scents stronger than normal individuals and gives them cough and headache.

To decide the scent-level in Volvo's cars there is a qualified test group who rates the scent on a six grade scale where 1 represents not noticeable and 6 unbearable. Volvo has decided to keep their limit for new car smell on 3 - noticeable but not bothering (Andersson, 2012). The Swedish asthma and allergy foundation has on the other hand set their recommended level for cars to 2.5 in order to minimize the risk of annoyance for sensitive individuals.

5.7.2 Air compound

Aside from the air quality in regard to perceptual factors it is also of importance to have the right compound of molecules and ions.

5.7.2.1 Negative oxygen ions

Oxygen ions exist in a balanced compound in normal outdoor-air. It has been found that positive oxygen ions can induce a feeling of nausea, fatigue, roaring in the ears, concentration difficulties and headache (Koller, 1932). Negative oxygen ions on the other hand are believed to create a feeling of exhilaration, reduce stress and increase the binding of oxygen to the hemoglobin (Mönkemöller, 2012). It is also believed to reduce the amount of carcinogen free radicals[15]. They can't be spotted by smell or any other sense but has a long term wellness effect and because of this long term effect it is hard to test how they affect humans (Mönkemöller, 2012). In the Asian market, where ionizators in cars are more common, a bit of ozone is usually added while the ionizator is switched on in order to make it perceivable to the sense of smell since this is something the costumers have requested. The customers like to be noted when the apparatus is in function and has therefore requested feedback that tells them it is on (Mönkemöller, 2012). Ionization is accomplished by passing the air through a high voltage electrical field. The molecules are then charged negatively. Ionization do not only improve the driver's wellbeing, it can also work as an air cleaner when combined with electrostatic filter. Many particles are so

[15] Radicals (often referred to as free radicals) are atoms, molecules, or ions with unpaired electrons on an open shell configuration. Free radicals may have positive, negative or zero charge. With some exceptions, the unpaired electrons cause radicals to be highly chemically reactive. Free radicals play an important role in a number of biological processes, some of which are necessary for life, such as the intracellular killing of bacteria by phagocytic cells such as granulocytes and macrophages. However, because of their reactivity, free radicals can participate in unwanted side reactions resulting in cell damage (The free dictionary).

small that they travel through the air filters and these particles can get into the lungs (Mönkemöller, 2012). The negative ions create a force that makes water molecules arrange around it and eventual dust and bacteria etcetera attach themselves to the ion which increases the mass and the cluster sinks to the floor (Mönkemöller, 2012).

Toyota has made an experiment with three groups of people to test the effects on stress levels of added scents and ionization while performing a task. The first group had only natural air to breathe, the second group had oxygen ions added to the air and the third group had both ions and added scents. A test of CgA[16] showed that the stress levels and amount of recovering time to base level decreased with each group. The best result was consequently reached with both ions and scent (Mönkemöller, 2012).

5.7.2.2 Carbon dioxide

Carbon dioxide is a natural part of the air and in our blood, but an unnatural high concentration of it can have severe and in worst case fatal implications (Luftvägar och lungor, 2005). Breathing in carbon dioxide can cause dizziness, nausea, vomiting, fainting and death (Williams, 1958). Scientific experiments on dogs have shown that a higher concentration of carbon dioxide in the blood can trigger vomiting if the person is already feeling nauseated. An experiment on mice has also shown that inhalation also can affect the olfactory[17] functions and increase the sensitivity of odors (Buron, 2009). The natural composition of air contains approximately 78% nitrogen, 21% oxygen, 0.0351% carbon dioxide and ozone and other inert gases in smaller concentrations (Ekstrand, 2011).

[16] CgA is a protein in the saliva (Steinke & Mönkemöller, 2012).
[17] Olfactory = Relating to or involving the organs or sense of smell (The free dictionary).

5.8 Patent search findings

Many of the found patents are different kinds of chairs or solutions that build on the idea of acupressure. The acupressure consists of wristbands that press on a special point to reduce motion sickness. According to researcher Joakim Dahlman, this method has no effect, though acupuncture has. This kind of medical treating is much debated and there is a lot of differing opinions among researchers.

The most interesting patents for this project are listed below:

1. One patent involve an artificial sound horizon that is believed to minimize motion sickness. This was developed for use on a ship. It has an apparatus that measures vertical and horizontal accelerations in an enclosed space. Sound emitters use the enclosure as a reference and vary the sound levels in order to maintain a stable horizon (Fergusson, 1992).
2. A vibration damper that damps audible vibrations and infrasonic frequencies associated with motion sickness. It is usable in many fields and is mountable between vehicle body shell and interior floor of the vehicle (Burton, 2003).
3. The first encounter with negative oxygen ions in this project was when the *dizzy proof cap* was found. It can be used to prevent car sickness, airsickness and seasickness and includes a negative oxygen ion generator (Hua, 2005).
4. The automatic balancing corona-protective chair is a chair that adjusts itself and keeps horizontal when the wheels jog or rock. This would help reduce car sickness, air sickness and sea sickness (Li, 2010).
5. Another patent intend to make driving more comfortable and reduce motion sickness for occupants in a vehicle. The patent comprises an indicating apparatus that informs the passengers, with the help of sound and pictures, when the driver accelerates, brake, turn left or right or if the driver brakes to make them more aware of what motion comes next (HIROYUKI, 2007).
6. Another patent that intend to reduce motion sickness is a driving support device that detects the position of an occupants head and notifies the driver that there is a possibility of car sickness (TAKERO, 2005).

7. Another interesting patent is a device that supply oxygen enriched air in order to reduce fatigue and car sickness (HIRONAO, 2005).
8. An apparatus for detecting and signaling potentially sickening motions to the steering system or the driver, have also been found in the patent search. When feedback is given, the driver can change the steering in a way to minimize unwanted motions (JELTE, 2005).

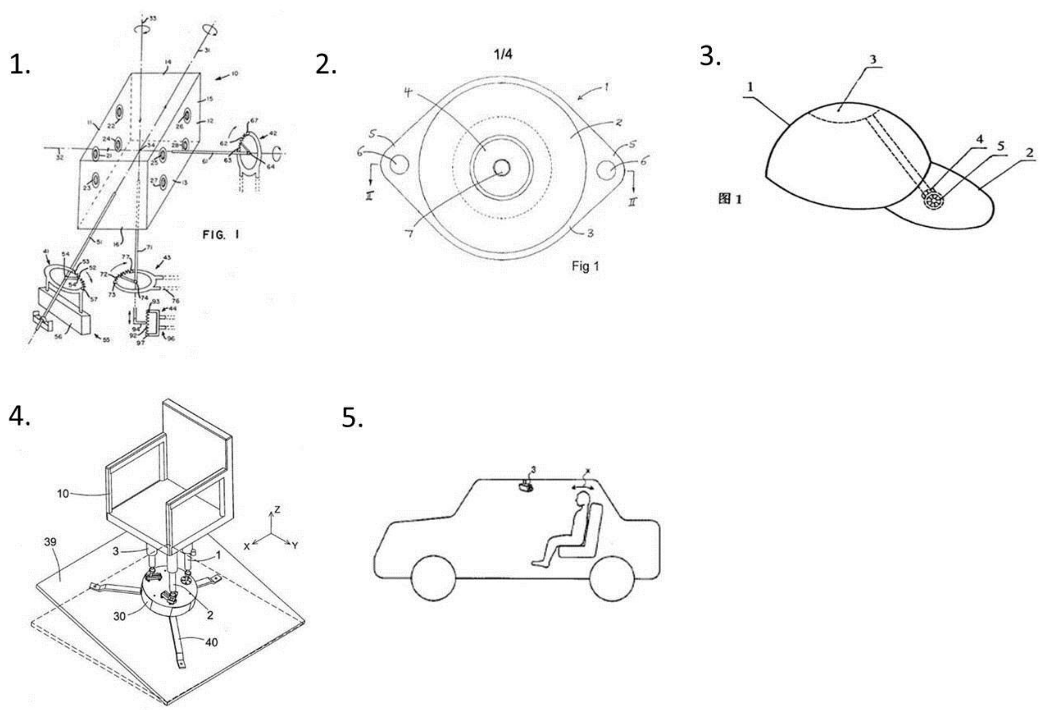

Fig. 20. Picture showing design and construction of some of the patents.

5.9 Personal interviews

The results from the personal interviews show that there is an individual difference in how you react from travelling in different vehicles. All three interviewees feel strongly affected by the spinning motions that can occur in amusement rides, while only one felt affected of travelling by train. Two of the interviewed felt nauseated by the swinging motion on boats, while the third said *“I don’t think boats are unpleasant either, it feels more gentle”.* This might be an argument towards the fact that motion sickness is very individual and might therefore be hard to fully eliminate. All three were also of the opinion that blocked vision frontwards in level with the horizon could trigger nausea which strengthens the argument that good vision and being able to refer to the horizon is a crucial part of the avoidance of motion sickness.

“I guess you can’t compare it to G-forces when it comes to cars, but when you are pushed to the sides of the car. Like when it’s a very sharp curve...and especially when it’s followed directly by another one, but in the opposite direction. I guess you could call it accelerating movements.”

This quote is from interviewee number three, though all three had the opinion that accelerating movements to the sides are unpleasant. Interviewee number two also thought that it is harder to focus the eyes on something when you drive fast on curvy roads which made her feel dizzy. This points out that movement in other directions than the vertical can cause discomfort and nausea. It is therefore important to consider movement in all directions as a possible cause of motion sickness. How you should address the problem with these motions comes yet again to depend on the individual differences. A compromise of which vibrations that should be the focus of elimination must be found, tentatively built on statistics from motion sickness tests combined with statistics of anthropology and physique from Volvo’s customers.

The belief that motion sickness is to a large extent psychologically induced is perhaps the strongest expressed by person number three that explains the phenomenon of motion sickness as follows:

“When you begin feeling motion sick you sort of loose your whole brain into it and it just gets worse and worse and escalates the whole time until you stop. If you were to take focus away from it, talk to someone or do something else, I don’t think it would get so bad.”

While person number one suggests that too much things taking focus away can have a negative effect:

"It usually feels calmer driving on your own, you're able to sit more relaxed too. It's stressing to take responsibility for the kids if you have them with you...to keep order."

One could draw the conclusion from this that a mild form of distraction that keeps the individual relaxed but yet occupied by something could be good for the avoidance of motion sickness. However, there lies a difficulty in this: the individual differences. It is hard to say what makes a person calm and what makes a person stressed since we all experience situations differently. For example, one person could be mildly distracted by a video game and feel relaxed while playing while another one could feel a great amount of stress. In another, calmer situation, one person could feel totally relaxed while another feels restless and experiences stress because of this. This obstacle could gain from being investigated further to find a compromise of an activity that relaxes the bigger part of the population but still keeps the mind engaged.

Another interesting thing found from the interviews is that leather seats aren't preferred because of two different reasons. Interviewee number one disapproves of them because of the inelastic quality it gives the headrest which, in its turn, intensifies the vibrations.

"/.../ *but I can feel a bit motion sick if I rest my head against the headrest or the B-pillar due to the vibrations. To stiff headrests aren't good, luxury cars are often better in this department. They have softer, a bit poofy headrests. Also fabric covers is better, leather is often too tightly stretched. "*

Interviewee number one also disliked the intense smell of it, as well as interviewee number three:

"I know I thought about it when I was younger that I had easier to feel sick in cars with leather seats than in cars with fabric. Not because I thought it smelled bad, but it smelled more new in a way...a more intense, trapped odor."

In a study made by Volvo in Sweden and in the Asian market customers have expressed reluctance to added smells in a car (Andersson, 2012). They were unwilling to pay for it and it is not a desirable quality in a car. They did, however, wish to have natural smells such as wood and leather. Since the interviewed persons in this project didn't really mind the smell as such, just the intensity of it, it might be a good thing to take under consideration to lower the odor limit which is for the present time set to 3 (Andersson, 2012).

To re-connect to the phenomenon of highly sensitive persons as mentioned in chapter 6.1.3 about individual differences, hunger and thirst could be a large part of developing motion sickness since this affects these individuals highly. All three interviewees were of the opinion that food and beverages could affect the condition both before and during the car trip. Interviewee number one liked to eat in advance while interviewee number three liked to eat during the trip:

"I often chew on something and try to take focus away from it. I usually eat candy, something that tastes a lot and gives variation. Chewing gum helps for a while, but when they lost their flavor it's just chewing and chewing.. "

Interviewee number two on the other hand said that menthol gum had a refreshing effect which points on the differences in personal preference. It has been shown that some tastes in general can cause nausea and some can prevent nausea. Bitter tastes like coffee, beer and chocolate can cause a nauseating feeling because the body reacts as if they are potential toxins (Newswise, 2011). Ginger on the other hand, is known to help minimizing nausea and motion sickness (Bloyd, 2007).

Besides the effect of drowsiness that many motion sickness drugs can cause that may be a performance reducer for the driver, there is also some other side-effects that can be quite unpleasant and make people reluctant to ingest them. Interviewee number three speaks of such an encounter:

"*I also tried motion sickness gum once but my jaw became numb so I was frightened and i spat it out."*

This suggests that there is a large market for motion sickness reducing means besides medications.

5.10 Focus group

The focus group session started with an open discussion around the subject of motion sickness based on the questions “What do you think causes motion sickness in general?” and “What do you do to feel relaxed in a car?” Focus was thereafter moved to discussion around the feedback symbol.

5.10.1 Discussion of experienced issues

Participants of the focus group described different kinds of motions which made them feel nauseated and the most common problem seemed to be for-and-aft movements that occurs while braking and accelerating. One of the participants had especially bad memories from for-and-aft movements:

“I remember one time when I was in Italy on vacation and we got stuck in a tailback for two hours and there were a lot of starts and stops. I just felt like walking out on Autobahn and puke.”

All participants agreed that a constant speed is an important measure toward motion sickness which is a significant argument for reducing for-and-aft motion. One of the participants thought that fluctuations in speed could be the reason why it is more comfortable to travel by train than by car since trains holds a more constant speed.

The lateral motion was also something that was mentioned as a cause of discomfort and nausea. This was, according to the group, a bigger problem on buses, especially on the top floor of double-deckers. One possible explanation to this, that was expressed by one participant, was that the fluctuations away from the up-straight direction was enhanced by the larger distance from mass center to suspension and that it therefore got more “swaying” in curves.

The group described the sensation of motion sickness as feeling hung over, a bit sick and feeling warm. One of the participants described the unpleasant sensation similarly to the sensation caused by alcohol intake.

“It’s like being drunk. You just want to pause everything, you can’t focus on anything else.” This resembles the mind-occupying sensation described by one of the interviewed persons. This suggests that, if one would decide to work further with the psychological part and taking focus

away, you have to divert attention preventively; before the individual starts being bothered and focused on the motion sickness.

One of the participants who had been travelling in Wales mentioned a road with thick, high hedges and quite short sight forward where she had felt car sick and another participant said that he could get dizzy from the peripheral vision. This is very similar to the quotation by the second person of the interviews and further more strengthens the idea that an isolated vision to the sides could remove one source of irritation. An opposition here is that the peripheral vision actually could be helpful when you can see far ahead and thus be able to relate to the horizon, and may only be disturbing when there is something flickering by fast.

5.10.2 Brainstorming feedback symbols

The participants of the focus group got to draw concepts and express thoughts around a symbol that could inform the driver when he/she is driving in a way that can cause motion sickness. There were many ideas of illustrating the low frequency vibration as a sinus curve, or as ocean waves as one of them said. Other ideas were to illustrate a shaking car in some way by stylizing a car and shaky lines around it. Another thought was to be inspired by other ways of expressing nausea by use of characters and symbols from comic books. This refers to using swirly lines or simplified facial expressions to resemble the expression of nausea.

The thoughts around coloring were to make it visible to the driver and have the symbol in a quite intense color yet not make it too alarming. Many of the participants therefore thought orange to be a good color for this purpose. There were also thoughts about linking the color to its purpose, like blue to symbolize ocean waves or a sort of green-brown shade to symbolize the vomiting and the obnoxious feeling of motion sickness. There was also an idea of showing a graded scale so that the driver could see how well he/she complied with the area of “good” frequencies and to sooner discover when it is going the wrong way as the meter gets closer to the “bad” frequency-ranges that cause motion sickness and discomfort.

Fig. 21. Notes from participants of the focus group during the brainstorming session.

Other ideas of concepts outside the area of feedback symbols were to counteract the vibration by a rotor that creates an equal vibration frequency shifted a half wave length compared to the vibration from the road surface to flatten out peaks and bottoms of the vibration wave as shown in fig. 22.

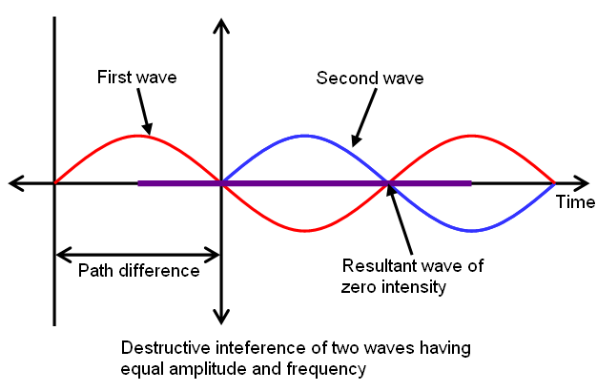

Fig. 22. Interference due to a shift of a half wavelength between two equal waves, so called destructive interference. Picture found at (Eculator).

A problem with this is if the vibrations arise as point sources in which case a misplacement of the counteractive vibration source would not only cause destructive interference but also constructive interference which would increase the total amplitude in those points where two peaks meet (Ph.D. Gibson). The rotor would in that case have to be placed at the exact same location as the source of the vibrations. There were also ideas of creating counteracting vibrations within the seat which would have to be adapted from the same criteria's.

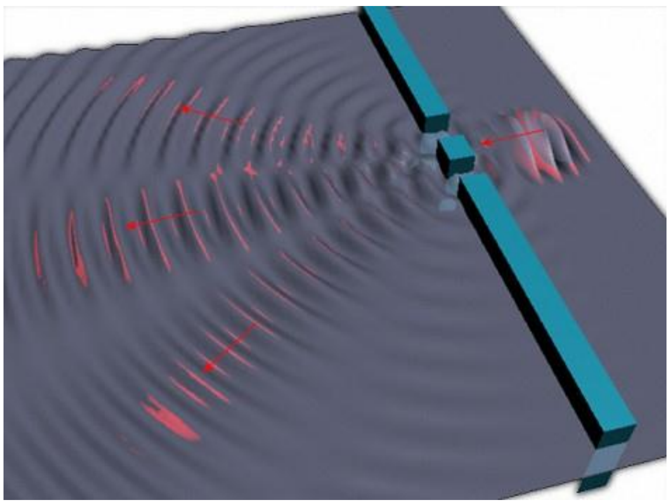

Fig. 23. Interference between two point sources creates both destructing and constructing interference. Constructive interference causes doubled amplitude and destructive interference creates a resultant of zero amplitude. Source: (Aether Wave Theory, 2009).

5.11 Design of feedback symbols

After the focus group, a meeting was held with PhD student and lecturer Lars-Ola Bligård who conducts research in the area of human machine interaction. Outcomes of this meeting were some tips of what to keep in mind when developing a symbol. According to Bligård, it is important to consider the use of a product before minding physical performance. The customer has to register that something has happened and what has happened. Another important point is to give guidance to what response or action the customer is expected to perform. After he has performed the task, feedback should tell him if the task was done correctly. It is generally more positive to indicate when something is working than just providing information when something is faulting. Bligård also gave the advice to consider the whole situation in a car and what other inputs and feedback the customer receives there.

6. Answers to research questions

Many questions and ideas were raised in the beginning of the project and most of them have been answered. Below is a list of the questions and short descriptions of the answers. It is also described where the answers are further described in the report.

Would it be beneficial to have things and buttons higher up so you do not need to lean forward in order to reach them? – This is believed to be a good idea because head alignment has a big influence on motion sickness. This is described in chapter 5.3.2.

Would it be beneficial to have good visibility forward and sideways? – A good visual field of view, especially forwards, is important in order to avoid motion sickness see chapter 5.5.1.

Is it worse to look out the window in a 90 degree angle than straight ahead? - The risk for disturbing "flickering" motions is bigger when looking to the side. See more in chapter 8.

How often does the frequency 0.2 Hz occur during normal driving?
Vibration frequencies between 0.1-0.5 Hz occur in cars but not of sufficient intensity to cause motion sickness, see chapter 5.4.3.

Is it possible to design a market offer that involves "anti car-sickness car"? – A conclusion was made that it is not preferred to have a market offer that involve a promise of an "anti car-sickness car". The reason for this can be read in chapter 8.

Should the new solution be included in the car without the customer knowing it is there? – A recommendation is to include solutions that minimize the risk of motion sickness without the customer knowing it is there, see chapter 9.

Would it be beneficial to have an upright sitting position - It has been found that posture have big influence of transmissibility from the seat to the head, especially during higher vibration frequencies. See chapter 5.4.3

What individuals suffer most from motion sickness? – It is most commonly children between 4-10 years that suffer from motion sickness and also so called HS-persons, see chapter 5.1.3.

How much influence does the way of driving have on motion sickness? – The driver can influence vibrations and motion primarily in horizontal directions and the way of driving is the main cause for horizontal vibrations arising. Vibrations in vertical direction are more connected to road and vehicle, see chapter 5.4.

Would it be preferable to have stiff chassis? – Stiffness of the chassi has little influence on the occurrence of low frequency vibrations in the range 0.1-0.5 Hz which is the worst cause to motion sickness, but makes difference in the area of 1-2 Hz, see chapter 5.4.3.

Is cool air beneficial from a motion sickness point of view?/ Does the temperature in the car have any effect on the drivers/passengers degree of motion sickness? – The preferred temperature in the cabin is very individual and depends on body temperature, wind and physical state. It is therefore difficult to set a value on this. See chapter 5.7.

Does fresh air minimize the risk of motion sickness? – It has been found that air compound of ions and molecules have an effect on the degree of nausea, see chapter 5.7.2.

Can smell trigger nausea? / Is there any smell that can prevent nausea? – The experience of smell is very individual and depends on sensitivity of receptors and former experiences. There is however a few smells that most experience as unpleasant or nauseating see chapter 5.7.

How should a market offer be formulated? – A conclusion has been made that the individual susceptibility to motion sickness makes it hard to give guarantees. The expectations can also due to psychological influence on motion sickness make the symptoms amplified by the mind. See chapter 5.1.3, 5.4.2, 5.6.1, 5.7.1 and 8.

Can sound trigger nausea? – Yes, see chapter 5.6.

Is there any audio frequency that can soothe the feeling of nausea? – There is no found evidence of a frequency that "cures" nausea, but there is a sound that resembles the sound we hear as fetuses in our mothers belly that generally makes people relaxed. See appendix no.2.

Many people feel negatively affected by infrasound just before a thunderstorm; can ultrasound have the opposite effect? – No, ultrasound can actually cause symptoms of nausea and fatigue. See chapter 5.6.2.

Can the organ of equilibrium be affected by sound/ sound absorption? – Yes. The vestibular organ is both affected by low and high frequency sound and experiments have shown that also sound absorption can influence us negatively. See chapter 5.6 and 5.11.3.

Are there any other research made on motion sickness other than within the marine, train and military area? – Yes. There is also research within the car industry, airplanes and space shuttles etcetera. See chapter 2.

How much depends on physical factors and how much depends on psychological when motion sickness occurs? – It is hard to put a number on the psychological part of motion sickness, but it is certain that mental state and stress level have a big influence on the development on motion sickness. See chapter 5.1.3 and 8.

Would it be beneficial to have hard padded chairs with side supports or to have side support for the head? – The seating and posture have great importance for how we experience vibrations and motion. Side support for body and head could minimize the uncomfortable heavy fluctuations that can occur from for instance driving fast through a curve. See chapter 5.1 and 5.4.3.

Would it be beneficial to have a feedback symbol when frequencies are close to 0.2 Hz? - A conclusion we have made is that the vibrations in vertical direction is hard for the driver to avoid since it depends more on road surface and vehicle. A feedback for horizontal directions could be developed, but should shift focus from the problem of motion sickness. See chapter 5.11.2.

Would it be beneficial to have a shedable headrest in order to create more visibility to the backseat passengers? – As wide frontal view as possible is the best and it would therefore be beneficial to have sheadable headrests on the frontal seats if there is no front seat passenger. See chapter 2 and 5.5.1.

Would it be beneficial to have integrated child seats placed high (Higher than they are today?) in order to create more visibility for the passengers – A higher seat could increase visibility both forward and to the sides since the heads position then is raised relative to the beltline. A higher seat can also be good for shorter adults but should then be more discrete. See appendix no. 2.

Would it be beneficial to have low beltline/ thinner A-pillar/ thinner B-pillar? – All changes that increase visibility is good unless they create disturbing visual elements like flickering motion. See chapter 5.5.1 and appendix no. 2.

Can you become motion sick when you are asleep? – No. There are no conflicts between inputs of vision and vestibular system because when we are asleep the brain does not analyze the input at all. See chapter 5.1.

7. Concepts and ideas

After thorough review of found facts and subjective information, a brainstorming session took place and a number of concepts were created. The concepts that follow recap the ideas within the subject areas of which a deeper research was made: vibration frequencies, feedback and market offering, low frequency sounds and air ionization.

7.1 Vibration frequencies

The difficulty with reducing motion sickness inducing frequencies is that materials and springs that damp vibrations in the car may cause the motion to get closer to motion sickness inducing frequencies of 0.16-0.2 Hz.

7.1.1 Communicative cruise control

Many commercial buses within Europe are soon to be supplied with a computer that communicate with red lights and give the bus driver a recommended speed to create a so called *green wave*[18] (Svevia, 2011). This decreases the number of brakings and is good for the environment since acceleration after a stop or retardation requires more fuel than when keeping an even speed. The invention also helps keeping a more even traffic flow. The computer could probably be connected directly to the cruise control to reduce the need for attention from the driver. The decreased number of brakings would decrease the longitudinal motion accordingly and hence increase the comfortableness for the passengers and decrease the possibility of motion sickness occurring.

7.1.2 Vibration absorbing materials

The way to reduce vibrations used today is to lower the frequency with the help of springs in the wheel suspension and seats. This lowers the frequency and creates a more comfortable movement for persons sitting in the car. This could however create a worse situation from a motion sickness point of view if the vibration frequency affecting humans become as low as 0.16-0.2 Hz. Another problem with the use of springs is that it may create a delay in the movements which enhances conflicts between vision and proprioception. It can also create constructive interfering and an amplification of wave tops and wave troughs since the springs

[18] Green wave = When all traffic lights are green when you arrive at the crossings.

make the movements more long-lasting which could cause one wave top to meet another wave top and vice versa.

A way to get around this would be to use materials in seats and car that absorb shocks and transform more of the impact energy into heat rather than just lowering the vibration frequency. An example of this is the visco-elastic polymeric material memory foam that deforms greatly to pressure and shocks and stops the vibrations from translating through the material. A downside with this material is the high price in comparison to other polymer materials. Another downside in comparison with springs is that it requires a quite large mass and space to make a difference and would therefore raise the total weight of the car. A middle path could be to use memory foam in removable car seats for children (who suffer the most from motion sickness) and thus use it only when necessary.

There are also other visco-elastic polymers, like for instance Sorbothane®. This is an American product used for soles in running shoes, body armor and acoustic and vibration isolation for industrial use etcetera (Sorbothane Inc., 2012). This material is claimed to absorb both vibration and shocks at the same time which, if true, would be ideal for the variations of the road surface that alters from small vibrations due to rough structure of the asphalt to larger impacts from holes or bumps in the road. It is also claimed to be more than twice as efficient in shock absorption as Butyl rubber and Neoprene (according to diagram in fig. 24). There is however a small time delay compared to the rubbers response to the input impulse which could have a negative effect on the conflicts between seen movement and experienced movement if the passenger can see the differences in the road and expect the car to move accordingly. But this is probably not likely since bumps in the road are hard to see for the passenger.

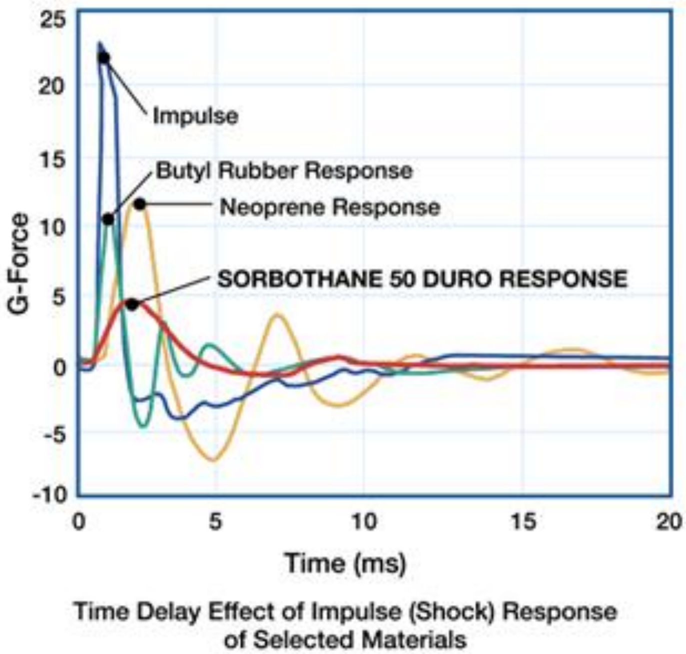

Fig. 24. Diagram over shock absorption for the material Sorbothane® compared to Butyl rubber and Neoprene. Picture found at (Sorbothane, 2012).

However, it might be beneficial to reduce small vibrations and large impacts regardless of delays since these are highly uncomfortable and can aside from discomfort also contribute to a feeling of nausea if the vibrations reach the stomach area.

7.1.3 GPS adapted for car sick individuals

A way to avoid unnecessary turns and vertical vibration is to choose a route that contains little of these factors. A GPS that give recommendations of routes based on their comfort level could be a way to reduce motion sickness. The information could be built on maps (for less turns and stops) and data from the Swedish road administration that has measured level fluctuations of the road. This evenness has been measured with lasers with the purpose to monitor the standards of Swedish roads (Genell, 2012). The recommended routes should be adjusted both after motion sickness inducing vibration frequencies as well as keeping within the area of comfortable vibration frequencies below the high-frequency area.

7.2 Feedback symbols

One of the objectives of this project was to explore the possibility of giving feedback to the driver of how to drive when motion sickness inducing motions and vibrations occur. Here follows a variety of options on how to solve this problem.

7.2.1 Driving feedback for motion sickness inducing vibrations

The vibrations in fore-and-aft and lateral directions that can occur while driving can partially be avoided by the driver. The lateral motions are much due to driving fast through curves and the longitudinal swaying depend on heavy accelerations and decelerations. The vibrations in vertical direction that occurs in cars are not intense enough to produce motion sickness according to M.J. Griffin and are also harder for the driver to avoid since these depend more on the condition of the road surface. The concepts around this feedback have consequently been focused on the horizontal movements in lateral and longitudinal direction.

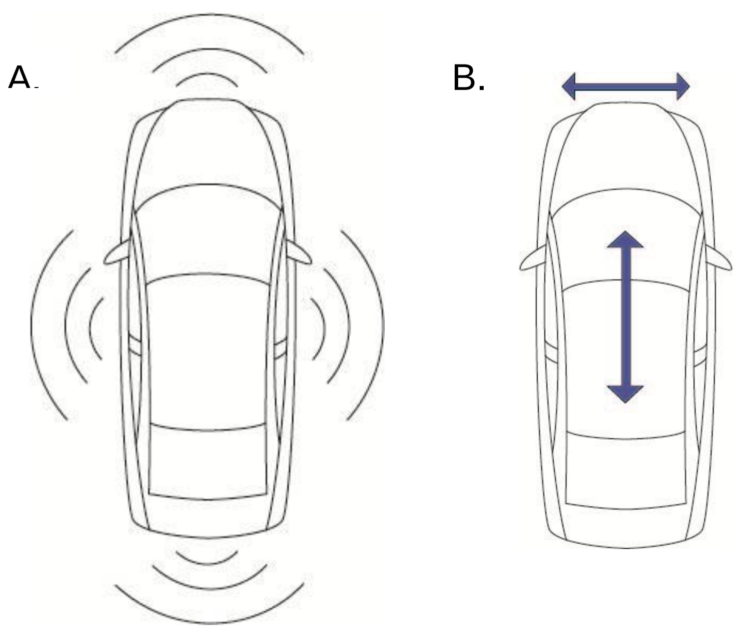

Fig. 25. Concepts of feedback for motion sickness inducing vibrations in horizontal directions.

Fig. 25 shows examples of feedback symbols that are meant to give feedback to the driver. Picture A shows vibrations illustrated by lines that could light up one by one depending on the amplitude of vibrations. The feedback can also be separated into whether the vibrations are lateral or longitudinal. This symbol is inspired by illustrations of motion and vibrations that often occur in other channels, like comic books and user guides.

Picture B shows a concept that is similar to A and the arrows are meant to light up when motion sickness inducing vibrations occur. One arrow represents fore-and-aft vibrations and the other represents lateral vibrations.

7.2.2 Eco-driving feedback

Instead of giving the driver a warning when low frequency vibrations occur, the driver could receive a notice of how well he/she drives in an eco-friendly way. The term *eco-driving* refers to driving in a way that reduces the CO_2 emissions. This means holding an even speed (preferably as low as possible), driving at high gear, avoiding unsmooth accelerations and releasing the gas pedal early instead of braking (The free dictionary, 2012). In particular the two latter would reduce the occurrence of for-and-aft motion. A decrease in this type of motion would probably ease the trouble with car sickness. The environmental friendly approach of the feedback would also take focus away from motion sickness and reduce pressure and stress from the driver.

Fig. 26. An example of an eco-driving feedback symbol. Source: (Advanced energy, 2011).

7.2.3 Comfort driving

Another way to take focus from motion sickness is to create a comfort symbol. This type of feedback could include vibrations in all three directions, but preferably in for-and-aft and side-to-side motion since those motions are the easiest for the driver to have influence on. The purpose of the feedback is to make the driver keep a more even speed, avoid heavy breakings and keep a slower pace in sharp curves in order to create more comfort for the passengers. This would reduce much of the bad vibration frequencies and increase well-being amongst the passengers.

Two sketches of symbols with the purpose to inform the driver about the level of comfort in the car have been developed in this project. They are both scaled to display gradually how comfortable the car has been driven the last five minutes.

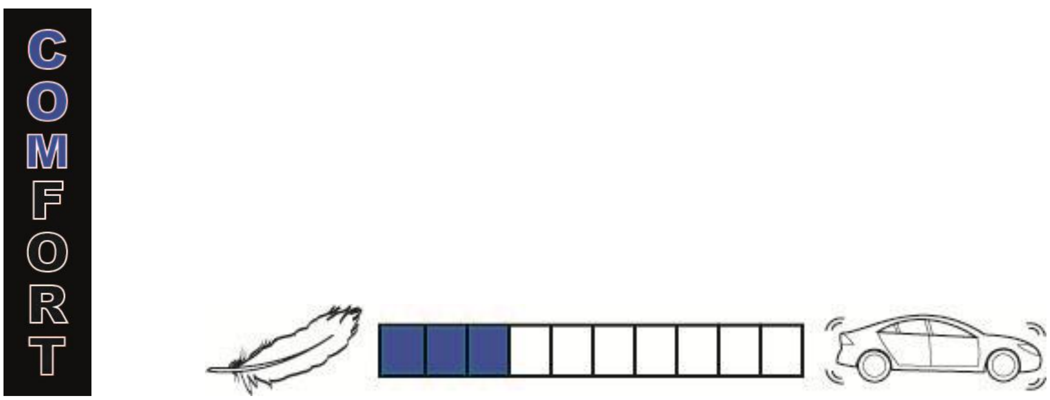

Fig. 27. These drawings show examples of a comfort symbol.

The letters on the symbol to the left in fig. 27 will be lit one by one. When all is lit, the car is driven in a fully comfortable manner. The advantage of using letters is that it is more understandable in situations where an instinctive symbol with high guessability[19] is difficult to find (Bligård, 2012), for instance for use in new functions or inventions where external consistency[20] is an inexistent measurement. But it might be hard to find an internationally marketable word, though English is understood in most countries and most often used for symbols, instructions and feedback.

[19] Guessability is a measurement of the cost (in time or errors) to the user in using a product to perform a new task for the first time (Jordan, 1998).
[20] External consistency is a measurement of how well similar tasks are performed in a similar way between different product brands (Jordan, 1998).

The symbol to the right displays an increasing level of comfort within the car the fewer fields that is lit. An advantage with using symbols is that they can be understood by illiterates and have no linguistic barrier, it might though be hard to find an internationally marketable symbol also in this case, but for other reasons than for the previous. Cultural differences make us perceive pictures and colours in different ways. It can also be hard to find symbols with good compatibility[21] and avoid misconception for new feedback functions.

7.3 Low frequency sound

The occurrence of infrasound in Volvo's cars has not yet been fully investigated and this would therefore be an important step to take. It is difficult to set a limiting value for the sound intensity in a car since the influence on human health is very different because some people have more sensitive hearing, and most limit values is not adapted to individuals with sensitive hearing. Limit values are normally set to match the influence on a human during an average eight hour work day which might be less common in vehicles. This means that an equivalent for shorter periods of time should be calculated since time of exposure is an important factor on the influence on health (Ryberg, 2008).

If higher pressure levels than the recommended are found, the next step will be to investigate whether the sounds can be prevented or not. The prevention of low frequency noise has been quite thoroughly investigated within industries where noise is a common source of injuries.

There has been research found that show that the frequency of 7 Hz in the sound pressure level of 120 dB can be masked by a white noise of 10 dB in the frequency range of 10-100 Hz (Landström, 1999). Although these masking sounds often prove to be very effective, there is a risk that the white noise is perceived as disturbing (Kjellberg, 1999). Another way to mask the sound is by acoustic filters, though the source of low frequency sound waves are harder to locate and is therefore harder to know which places to isolate. Sound absorbers could also be used to absorb the sound inside the coupé and decrease the level of infrasound in the car. These absorbers lower the level of disturbing noise but are still not as good as a naturally quiet environment. An experiment of performance on school children when under the influence of

[21] Designing for compatibility means ensuring that the way a product works fits in with users' expectations based on their knowledge of the 'outside world' (Jordan, 1998).

noise showed that a sound isolated environment increased the level of performance compared to an environment with disturbing noise. Still, the performance level was not as high as in the naturally quiet schools (Hygge, 1999).

Another approach to the avoidance of noise is to prevent it from emerging. Since low frequency noise can originate from the tires (so called air pumping) and from loose fitted boot covers or doors that move back and forth because of differences in air pressure, a lot could probably be prevented at an early stage. Thicker insulating strips or other materials could probably decrease the problem with vibration noises from car doors and boot covers.

8. Discussion

The issue with motion sickness could be tackled from two different directions: From the ones who already are troubled by motion sickness and from the ones that have not already been affected. The first would probably benefit from a more psychological viewpoint while the second probably would benefit from mainly attacking the physiological shortcomings to stop the symptoms from ever occurring. Whether one chooses to go one direction or both at the same time, one follows the other and it is hard to separate physiological influences from psychological and this has also been one of the biggest difficulties encountered during this project.

Information search

The information search was meant to be wide with no limitations in the beginning of the project, but it was found that many of the used words and phrases led to a very large amount of results. When searching for "motion sickness" at Chalmers library website it brings 20099 results. It was therefore decided to search for answers to the questions asked in the beginning of the thesis work. This was a good decision because it would take too long to go through all of the found literature. It also made it easier to find useful information because the search results were narrowed down to more concrete information and easier to grasp.

The patent search of this project was a quick and easy way of retrieving information from many different areas. It was also good to find new areas of motion sickness prevention that were harder to find from the information search in the library databases though many of the patents were Chinese and often lacked translation other than for the summary. This made it sometimes difficult to grasp the whole concept of the inventions.

Market offer

Even though there is a market for a car that minimizes the risk of motion sickness, there could be a risk to use this as a market offer. One disadvantage is that people could become more aware of their symptoms if they focus on them which would make the sensation of them more intense. Hence, they could be disappointed that the motion sickness reducing measures did not prevent their symptoms as promised. Another reason not to mention motion sickness as an argument in a market offer is that it is difficult to design a solution that would eliminate motion sickness amongst everyone due to the individual differences.

Feedback symbol for low frequency vibration in horizontal direction

The positive outcome with using a feedback symbol is that it could change the driving behavior and decrease the occurrence of nauseating vibration frequencies and therefore also reduce motion sickness. A negative outcome with using this is that the driver's performance capacity may be reduced because it would add to an already information rich environment that exists in a car and would require attention from the drivers part. The implementation of the feedback symbol in a current existing feedback such as the eco-driving symbol would therefore be preferred.

A consideration one must have in mind if developing a feedback symbol for motion sickness inducing vibrations is that the function must be adapted depending on if the vibrations and motions occur frequently or more seldom. If the vibrations are rare, the symbol could be designed to give feedback, for instance light up, when they occur and otherwise be based on the presumption that everything is as it should and stay in the base position. If the frequencies occur often, this way of feedback could on the other hand be disturbing and irritating for the driver and a scale would in this case probably be more suitable.

Infrasound

The difficulty with setting limiting values for low frequency noise in cars is that the audible threshold is very individual and it is also unknown how many of those suffering from motion sickness that also have sensitive hearing and thus reacts negatively to infrasound. The lower audible threshold for younger individuals probably makes them more sensitive to low frequency noise and could explain why children suffer more from motion sickness than adults.

Besides the fact that existing limiting values are developed to suit normal hearing individuals, they also only exist for eight hour work days. So the question is if the values should be recalculated for an average time value for a car ride, or if one should assume a worst case scenario of an eight hour drive (or longer) and leave the values as they are.

Another difficulty is to decide under what conditions these limiting values should be valid. There are elevated levels of infrasound when windows or car roofs are open. The road surface and vehicle speed also have an influence on the noise intensity. A standard for these factors must first be decided to be able to evaluate if the noise levels are acceptable or too high. A question that has been left unanswered by researchers is whether the air conditioning in the car adds to the level of infrasound, as ventilation does in buildings. This should be examined during the tests of sound intensities.

Vibrations

From an environmental point of view it is better to have a smaller, lighter car that is low to the ground to reduce air resistance and thus fuel consumption. Though, from a motion sickness point of view this is worse because of two things:

- There is increased road sound from the smaller distance to the ground. Less material also often creates a poorer isolation towards sound from the outside and engine. An electric car on the other hand probably creates less sound from the low frequency range and reduced sound overall due to less engine noise and could be better because of this.
- The light weight increases the vibrations in the high frequency range since the car does not weigh down the springs in the wheel suspension as much which can make the car more uncomfortable (Hibbert, 2008). On the other hand, the vibrations in the low

frequency range are rarer than in heavier car models which could be good from a motion sickness point of view.

Visual system

There are large individual differences in the susceptibility towards visual input in the context of motion sickness. It could for instance be worse for some people to watch television or read in a car, while others could feel relaxed by shifting focus from the situation of riding in a car. It seems however like there is a larger group that benefits from a larger visual field of the outside. It might be hard to make a change in the design of a car with the purpose to minimize motion sickness since design constraints often restricts the possibilities of constructing a car entirely from ergonomic criteria. A compromise could be to use artificial horizons of light or sound.

Another question around preferences of visual input is whether or not the peripheral view is disturbing or helpful. Some have expressed the opinion that it would be nice to screen off the side windows because they become bothered by the flickering images and lights, while other say they feel helped by the additional view and that they are better able to refer to the horizon. An assumption that is made in this project, supported by the theory of researcher Anders Genell, is that the peripheral vision can be helpful when you have a long visual field and oversight of the horizon but that it can instead be disturbing and may create nausea if the visual field is short, with trees or houses close by, which causes flickering movement of the outside world. This could also be an additional explanation to why many are more affected by motion sickness when seated in the rear end of the car where the vision to the sides is almost larger than the visual field forward.

Proprioception

If you were to develop a system for compensation of GIF it would be of extreme importance to avoid delays between what the eyes see and the human expect and what we actually experience from the compensating motion. One example of this that is explained in chapter 6.3.2 is the X2000 trains that had compensatory alignment caused many cases of motion sickness among their passengers (Persson, 2011).

Another idea that has been discussed during this project is whether the passengers in the backseat are more affected because of the limited visual field or if it is because of a difference in the construction of the seats. The back seats are for instance closer fastened in the chassis which could be a source to a larger transfer of vibration. The front seats on the other hand have a construction that elevates them from the chassis. There is also a difference in material composition and inner construction that could make a difference in transfer of vibrations to the passenger and of the frequency range of the vibration that reaches the passenger.

Psychological

It is important to consider the fact that motion sickness is very individual and there is probably no solution that suits everyone. It is also hard to put a number on the psychological part of motion sickness since there is a lot of factors that can have a negative effect on the mental state and sometimes physiological input can be amplified by the mind. For example bad smell is something that we physiologically are meant to dislike and resist to protect us from food poisoning. However, which smells we find foul is very individual and can have an explanation in physiology due to a more sensitive sense of smell but also depends much on earlier experiences and our memories of the odor.

The psychological state of Highly Sensitive Persons, as mentioned in chapter 6.1, could perhaps partly explain why some suffer more from motion sickness than others. The deeper analyze of visual input could probably strengthen the conflicts between visual input and perceived motion and the input of sound and odors could increase the stress and mental fatigue and so lead to discomfort and a higher probability of motion sickness.

One difficulty with using distraction or relaxation as a cure for motion sickness is that people experience situations differently. A situation that makes one individual relaxed could make another feel stressed and vice versa. A criterion for using activation or relaxation must be to find a compromise that suits the largest population group or to offer alternatives.

Another thing to keep in mind is that the drivers performance level can be affected if their children or other passengers become motion sick. This can be quite distressful and it shows that motion sickness not only affects the person that suffers from it, but also people around them.

Other subject matters

One of the difficulties with improving a car from a motion sickness perspective is that if one thing is improved or eliminated, another can be focused on to a higher extent and perceived as more bothering than before. Another difficulty that almost all car developers face is to find room for additional gadgets without increasing the total weight. There is also the question of material cost and high cost for new technology that might be hard to motivate to the customer, especially if there is not any way to market the car's improvements.

9. Conclusion

One of the encountered difficulties during this project have been the question of whether a car could be designed to reduce motion sickness or not, because of the individual differences and psychological part of car sickness. A car could perhaps be designed to prevent the development of motion sickness among those who do not already suffer from it and can hopefully also be improved physiologically for those who are already troubled by motion sickness but might not eliminate the problem entirely due to the psychological stress that follows from earlier bad experiences.

Due to the large psychological influence on the development of motion sickness within many individuals, a market offer that focuses on the subject would not be preferred because of the risk that it could increase the problem or raise excessive expectations. It is therefore also difficult to develop a feedback symbol for this specific problem without drawing negative focus to it. The recommendation of the authors of this report is to include the feedback in a bigger perspective and not associate it with motion sickness but still influence the drivers behavior, like for example a comfort- or eco driving-symbol would do. In this case, the eco driving-symbol is preferred since it is a widely known term and most people already know how to change their driving behavior in order to adapt to the feedback.

An environmental approach would also reduce pressure on the driver since not driving in an eco-friendly way is not always related to being a “bad” driver as much as driving in an uncomfortable way is. Hence, it would not be as embarrassing for the driver if the passengers could see the feedback symbol.

Apart from driving behavior, the most important aspect of counteracting motion sickness seems to be reducing conflicts and delays between sensory inputs. Good vision forward and oversight of the horizon seems to be one of the most important parts in achieving this. This is also a recommendation made by Michael Griffin (Griffin M, 1990 p.322). Visual input overall is an important factor since visual stimulation itself can cause motion sickness. There is a divergence though between design and ergonomics that has to be overcome in order to solve the problem of restricted vision of road and horizon that exists in cars and create an attractive car that still is very highly ergonomic.

Another divergence that seems to exist is the one between motion sickness and the concept of comfort. The low frequency vibrations that can cause motion sickness are namely better from a comfort perspective. Hence, it is at present time strived to keep the vibrations at the lowest frequency possible. These two contradictions need to reach a compromise that includes both the classic take on comfort as well as acknowledging motion sickness as a problem from the human comfort perspective. An optimum setting with not too high, and not to low frequencies need to be found.

A recommended value for vibrations in lateral and longitudinal directions is to keep in the range between 0.5 Hz and 1 Hz. In the frequency range below 0.5 Hz there is a large risk for development of motion sickness and in frequencies above 1 Hz it is hard for the muscles to keep an upright position. (See more in chapter 6.4.3.) If the back rest were to be designed with better support in horizontal direction the vibration could slightly over-exceed these limit values. Vertical vibrations are most uncomfortable at the 5 Hz frequency and should thus be avoided. The vibration frequency in vertical direction of 0.2 Hz that is mentioned in the purpose of this project does not seem to be a primary source of motion sickness in cars.

Adding negative oxygen ions and reducing low frequency noise is something that could be helpful in preventing motion sickness. Though the effect of these on human health is not something that most people are aware of and the subjective data collected during this project shows little or none knowledge of the connection between these and the phenomenon motion sickness. They are however mentioned in several scientific reports as large health influencers. It is hard though to put it in relation to other motion sickness inducers, such as visual input and vibrations, and it is hard to tell which of them affects human health the most in a car. These two factors are also difficult for the individual to perceive and it would be harder to recognize a difference from other cars than for example a decrease of vibration or increase of vision would pose. It would however be worth investigating closer and to perform tests to see how large difference they compose, if eliminated.

A conclusion made is that it is positive if the individual is relaxed, and it seems to be a good thing to take focus away from the whole situation. Especially for those who already suffer from motion sickness and that might feel stressed beforehand. How this focus shift shall be achieved must be further investigated, but a guess is that social activities is both relaxing and de-stressing for most people. A first and simple step to reducing the psychological stress could for instance be to develop an app for Volvo’s customers with popular car games, quizzes etcetera than can be played in a car with preferably several participators. This is probably also the best approach to deal with the psychological stress within children who often gets easily restless and uncomfortable when sitting in a car for longer periods. Similar apps already exist on the market.

10. Recommended further work

This chapter is censored.

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12. Appendix

Appendix no.1 - Personal Interviews

Interview questions:

1. Is there any situations in general where you experience motion sickness?
2. Could you tell us about the situations when you experience motion sickness?
3. In which vehicles do you experience this sensation? (Boat, car, train, airplane, amusement rides or others)
4. How serious are your symptoms and at what age were you most affected?
5. Do you have any tricks or precautions to reduce the sensation?
6. What do you believe trigger motion sickness?
7. Do you feel sick or experience headache before a thunderstorm?

Car related questions:

8. How serious are your symptoms and at what age were you most affected?
9. Do you have any tricks or precautions to reduce the sensation?
10. Do you feel stressed or worried before a car travel? Do you ever feel sick in beforehand?
11. Is there any difference between sitting in the front seat and sitting in the backseat?
12. Do you have asthma or higher sensitivity towards smells? Are there any smells in a car or otherwise that affects you physically? If so, which?
13. How do you normally sit in a car? (Angle of backrest, position of body). Do you experience any difference in the development of motion sickness by the way you sit or the way you lean your head?
14. Is there any difference between daytime and nighttime? If you're alert or tired?

Answers:

Interviewee no. 1, female xx years.

Could you tell us about the situations when you experience motion sickness?

It usually feels worse if you're sick or tired, if you haven't eaten enough, have fluid deficit or if you recently worked out. Also when you are tired because you've gotten up early in the morning to catch a plane.

When you have more active control and steer yourself it's usually better, but if I drive very intense (heavy accelerations to the side and breaking) I can still feel a bit motion sick. And when you drive at a test track and have focus on the road quite near the car, it often feels better to have focus further away towards the horizon.

It shoudn't be to hot and moist either, fresh air instead. But once you started feeling nauseated you often get chills and then you probably would like to have it a bit warmer in the car. All impressions is actually enhanced when you get nausea; sound, sense and light sensitivity. I haven't particularly thought about lights as much in cars, but I thought about it on boats when it has been very strong, flat light.

In which vehicles do you experience this sensation? (Boat, car, train, airplane, amusement rides or others)

I can feel dizzy when riding carousels, swings, trains, boats (even on smaller boats like kayaks sometimes). Vehicles at all really.

How serious are your symptoms and at what age were you most affected?

I usually just feel a bit dizzy, on the boarder to motion sickness. When I was younger I didn't have as much problems with swings, but it was on the other hand worse in cars. It happened occasionally that I puked. But I have really never been able to read and things like that in cars.

Do you have any tricks or precautions to reduce the sensation?

Usually I just feel like going to bed, to have peace and quiet around me. I normally fall asleep quite easily too, but of course you can't do that while driving.

I try not to think about it in forehand either. If I'm about to drive at a test track for example I try to arrive there a bit earlier so I have time to unwind in between. I also try to eat and drink before so that I'm not hungry or thirsty when driving later.

Does it feel better if you close your eyes?

It feels better if you're about to fall asleep but if you're tense it worsens. The relaxation is probably more important than whether your eyes are closed or not.

What do you believe trigger motion sickness?

Movements in vertical direction is generally better than spinning motions, but combined movements in vertical direction with for instance heavy breaking is pretty bad too. And when you can't look out the window. It's not as good to look out the side windows as the front window, but rather that than no vision at all. Side movements is probably not that bad. Slow movement up and down on the other hand is rather bad, low frequented motions. I often feel better in low cars since they're bumpier than I do in larger, more swaying cars.

Do you feel sick or experience headache before a thunderstorm?

Yes, I can feel a bit affected by the weather. I can feel a pressure...and discomfort A bit headache too I guess.

Do you feel stressed or worried before a car travel? Do you ever feel sick in beforehand?

I don't feel stressed in forehand, but I believe per se that a certain amount of stress could be good too. That you're more present in the situation probably reduces the risk of nausea. I believe it depends a lot on hormonal state too.

Otherwise it can be rather bothering with many impressions at the same time too when you're sitting in a car, but I don't normally feel distressed mentally. Maybe it's just the body that gets stressed out. If I ride along when others drive I don't feel worried either. Stress in that situation could probably have a great effect otherwise, if you're afraid of crashing.

Is there any difference between sitting in the front seat and sitting in the backseat?

It's worse in the back seat than in the front seat. It's probably due to the lower comfortableness level. It's probably also due to a mixture of sight and movement. Sometimes you sit too far down so that you can't see anything because of that the seats are in the way. And if you sit too high up it feels clamped instead.

Some people though likes to sit further down compared to the belt-line which makes them feel safer, like in a cocoon. Such things could have a positive effect on the concern. Others would feel confined instead, so it's probably very individual.

Do you have asthma or higher sensitivity towards smells?

I don't have any asthma or sensitivity towards smells. However, I'm very sensitive to pressure changes. Perhaps I have tight ear canals or something. I tend to sense when the air conditioner is readjusted. Tightly sealed cars are usually worse because the pressure change is more apparent there. I can also feel a sense of discomfort when I walk in to a sound proof room. I can also feel nausea when I'm skiing because of the difference in altitude and pressure. It's the same with air planes. Low frequency sound and noise is also unpleasant....perhaps high pitched noise too. It usually gets worse when I have a cold; it kind of creates a higher pressure on the ear canals.

Are there any smells in a car or otherwise that affects you physically? If so, which?

The experience of smells is actually very bound to the air quality as well. Certain car smells can be a bit sickening. Paint thinner, alcohol, smoke (although it might not be as common in cars nowadays), petrol and exhaust gas are a few of those smells. Leather and plastics can also smell quite a lot sometimes. But I believe recognition is a big part of it. I'm so used to Volvo's car smells so I don't notice it as much. It is probably the same thing with smells as the others that mental state is a crucial part of how it affects you.

I can sometimes feel almost a bit nauseated by colors as well sometimes. Once i drove this car that had a mocca-beige interior that was not so fun. So color impressions could probably play a role in it as well.

How do you normally sit in a car? (Angle of backrest, position of body).

When it's to test something I sit very straight, as when you're driving. Otherwise I sit very relaxed, kind of slouch and rest my legs on something. I think it helps to sit a bit more relaxed but I can feel a bit motion sick if I rest my head against the headrest or the B-pillar due to the vibrations. To stiff headrests aren't good, luxury cars are often better in this department. They have softer, a bit poofy headrests. Also fabric covers is better, leather is often too tightly stretched. It usually feels calmer driving on your own, you're able to sit more relaxed too. It's stressing to take responsibility for the kids if you have them with you...to keep order.

Is there any difference between daytime and nighttime?

Nighttime is usually worse if you're driving or if you have to be awake by other reasons. The horizon disappears and you can't focus on anything further ahead. It's harder to see which direction you're going as well. It's better though if you're riding along with someone else driving 'cause you can fall asleep then. How many light-flashings from oncoming cars or street lights also affect your mode since it disturbs the vision.

Other thoughts on the subject?

How much information you receive from the car is probably also very affecting, and if you can disconnect it from your conscience or not. Light setting in the car is also affecting. It can feel disturbing with bright lights and intense colors, like red, it's harder to ignore. Green light often feels kinder, red is more aggressive. Projections on the wind shield can also be disturbing. It kind of disturbs the way you refer between the car and road. It's better with information closer to you and moderately is best - not too many and not too few impressions.

Interviewee no. 2, female 26 years.

Could you tell us about the situations when you experience motion sickness?

I'm more susceptible to motion sickness if I'm thirsty. I can also be affected when it's really bumpy or when there is a lot of bends on the road. It swings extra unpleasant when you're driving with a moving trailer. I can rarely read in cars too.

In which vehicles do you experience this sensation? (Boat, car, train, airplane, amusement rides or others)

Mostly in amusement rides, I can't stand spinning motions. Sometimes in cars. Apart from those I don't have any trouble with other vehicles...not air planes, not trains...I don't think boats are unpleasant either, it feels more gentle.

How serious are your symptoms and at what age were you most affected?

I haven't vomited since I was little but I've been close a few times. It was worst when I was four or five years..something like that...and before that as well really but I don't remember that. Worst case scenario was when you had been at grandma's and been stuffed with food and you had to go back home late in the evening.

Do you have any tricks or precautions to reduce the sensation?

I try to drink water and look far ahead on the road so I know what's coming. Menthol gum can help sometimes, it feels refreshing.

What do you believe trigger motion sickness?

When you go fast on curvy roads and you don't have time to focus your eyes at something fixed, you don't have any horizon to look at either.

Do you feel sick or experience headache before a thunderstorm?

No...I don't think I'm troubled by that...but I sleep restless when it's full moon. Maybe that has something to do with it?

Do you feel stressed or worried before a car travel? Do you ever feel sick in beforehand?
No I've never experienced that.

Is there any difference between sitting in the front seat and sitting in the backseat?
I can get motion sick when I sit in the back even if I'm looking ahead at the road. It's probably because it's bothering with the vision through the side windows, so it's always better to sit in the front seat. If you're not sitting reading maps in the front seat, then I can feel it as well.

Do you have asthma or higher sensitivity towards smells?
Yes, I'm odor-sensitive and I have asthma.

Are there any smells in a car or otherwise that affects you physically? If so, which?
I used to be more sensitive towards smells when I was younger, but there's still some smells I'm sensitive to. Like garbage stench, warm milk, old fish and diapers. It can be troubling with intense smells as well, like Wunderbaums and perfumes.

How do you normally sit in a car? (Angle of backrest, position of body).
When I'm driving I sit quite straight, otherwise I sit relaxed with angled back rest if possible.

Is there any difference between daytime and nighttime?
No I don't think so.

If you're alert or tired?
No.

Other thoughts on the subject?
No.

Interviewee no. 3, female 22 years.

Could you tell us about the situations when you experience motion sickness?

When you begin feeling motion sick you sort of loose your whole brain into it and it just gets worse and worse and escalates the whole time until you stop. If you were to take focus away from it, talk to someone or do something else, I don't think it would get so bad.

In which vehicles do you experience this sensation? (Boat, car, train, airplane, amusement rides or others)

In amusement rides, sometimes in cars, boats (both big and small ones). I have been feeling a bit sick in air planes sometimes...though I don't know if it's because of motion sickness....but it has to be because of that I guess..? Yes..

How serious are your symptoms and at what age were you most affected?

From what I can remember it has always been equally bad. I've never vomited but if feel nauseated and become faint and tired.

Do you have any tricks or precautions to reduce the sensation?

I often chew on something and try to take focus away from it. I usually eat candy, something that tastes a lot and gives variation. Chewing gum helps for a while, but when they lost their flavor it's just like you're chewing and chewing.. I also tried motion sickness gum once but my jaw became numb so I was frightened and I spat it out.

If I have already become motion sick I try to look far ahead, at the horizon, and focus on something else. I try to start talking to someone, and laugh. That usually helps a lot.

What do you believe trigger motion sickness?

I guess you can't compare it to G-forces when it comes to cars, but when you are pushed to the sides of the car. Like when it's a very sharp curve...and especially when it's followed directly by another one, but in the opposite direction. I guess you could call it accelerating movements.

And if the road is like wavy. Bumpy roads on the other hand aren't that bad. If there's a speed bump I like to go fast over it because I like the feeling in the stomach, but I don't like it when there is multiple bumps short after each other. I can’t stand amusement rides that are like that either.

Do you feel sick or experience headache before a thunderstorm?
Yes, I can get a headache from thunderstorms, but I haven’t noticed any difference in condition when it comes to pressure differences.

Do you feel stressed or worried before a car travel? Do you ever feel sick in beforehand?
No I’ve never experienced that..

Is there any difference between sitting in the front seat and sitting in the backseat?
Well, it is easier to look straight ahead at the road when you sit in the front seat. When I sit in the back seat I usually sit leaned against the door and try to look at the road in between the front seat and the B-pillar.

Do you ever feel bothered by the vision through the side windows?
No, I don’t think so.

Do you have asthma or higher sensitivity towards smells?
No nothing like that.

Are there any smells in a car or otherwise that affects you physically? If so, which?
I know I thought about it when I was younger that I had easier to feel sick in cars with leather seats than in cars with fabric. Not because I thought it smelled bad, but it smelled more new in a way...a more intense, trapped odor.

Is there any smell that makes you feel better?
No, not that I’ve noticed.

How do you normally sit in a car? (Angle of backrest, position of body).

When I sit in the front seat I sit quite relaxed and tilted back. In the back seat i sit leaned against the door.

Have you ever felt bothered by vibrations in the door or headrest?

No.

Is there any difference between daytime and nighttime?

No, not that I noticed.

If you're alert or tired?

No.

Other thoughts on the subject?

No.

Appendix no.2 - Other ideas

Some of the ideas and concepts produced have no direct connection to the four areas in which the second scope resulted and are therefore described in very short here.

Visual field

- If the B-pillars would be removed to increase the visual area for the passengers, the force from crashes could be passed through the floor instead of the roof. A protective frame over the roof that is triggered if the car would tip over (and otherwise hidden) would also eliminate the need for permanent pillars that blocks the vision for the passengers. If the forces were to pass through the floor instead, it might also be possible to design remaining pillars slimmer and thus enable the widest field of view as possible.

- In order to increase the back seat passengers' frontal view and view of the horizon, a "periscope" can be used or a combination of mirrors near the side windows can enable a frontal view instead of a peripheral view.

- There could be a camera that registers the eye-movements of the driver and the things that the driver sees can be shown to the back passengers. The purpose with this would be to enable the passengers to follow GIF and adjust their posture in beforehand to meet the acceleration force.

- A movie that contains a fake horizon which follows the real horizon could be displayed on the windows in the back and on a screen in between the front and back of the car (like in taxis and limousines). This "limousine-screen" could act like the windows used in interrogation rooms with ability to see through from one direction so that the driver can keep surveillance over the children in the back.

One purpose of the movie would be to distract the passengers and make them relaxed while riding in the car. Researcher M.J. Griffin support this idea that entertainment for the passengers would be good if it does not demand frequent head and eye movements (Griffin M. , 1990, s.322). The fake horizon would also compensate for the lack of oversight over the real horizon and give the passenger clues of how the car moves in relation to this. The movie could be a recording from a safari or other eventful environment with information about the animals or a story told in headphones or in the car's speakers. The sound tape could be combined with a fake sound horizon as well to enhance the substituting input. Another idea involves the passengers to wear "movie-glasses". This would include a bigger possibility of individual choices, as for example if there is both an adult and a child sitting in the back seat, they could watch different movies at the same time. The movies could also be in 3D to increase the realistic feeling, though this requires that the image is clear since blurry images are harder for the eye to focus on.

- An idea for marketing of the car could be to show images of things that people find relaxing very swiftly during commercials or in the car, and in this manner "trick the brain" into feeling relaxed and to have a positive opinion of the car. There have been experiments on this before that shows that our brain can register images even if they are shown under such short time that we do not interpret them or remember them afterwards. We can in thus be influenced to think in a certain direction without knowing we have been duped.

- The windows in the back could sense when the outside light is flickering and tint itself automatically to decrease the visual disturbance. Or there could be a curtain that pulls down automatically.

- There are patterns that can cause nausea through visual illusions of movement. For instance graphical striped patterns in black and white. Vice versa, there might be patterns that reduce motion sickness that could be used for patterning or structure of car interior (must be further looked into).

Seat

- The seat could change form by inflating air pockets or self-adjusting tension in springs to support the passengers in order to prevent them from moving in opposite direction of GIF. The safety belt could also be designed to be more similar to a racing belt which would give better support to the sides and help keeping an upright position. The uncomfortable tosses in lateral direction would so be counteracted.

- The seats could register the passenger’s weight and contact area in order to make a suitable adjustment of the suspension so that the vibrations in vertical direction is kept on a suitable frequency level since the human body is affected differently by vibrations depending on the individuals body structure. This idea may also be applicable for the whole car. The car could adjust the spring system in the wheel suspension depending on the total weight of the passengers and luggage.

- The seat could be raised in order to enable children to lean their head against the headrest and to give them a better view. It is possible that it is less embarrassing to raise the seat with a button instead of adding an additional cushion. This would also be better for adults of short length.

Alignment with GIF

- The kids could have a screen in the back that displays a live recording of the real road and a steering wheel that moves exactly like the real steering wheel so that they are prepared for how the car will move next so they can adjust their posture automatically with the acceleration direction.

- The chassis or the seats could tilt when the car turns to counteract the accelerating movement (similar to tilting trains).

- GVS headphones that affect the vestibular system with electric impulses might be able to use within a car with the purpose to let the passengers adjust them themselves or the car could adjust them automatically. This might minimize motion sickness because the passengers would feel as if they were travelling linearly.

Psychological

- People that get stressed out just knowing that they are going to be in a car might be helped if the feeling of being in a car can be minimized. This could be done with the help of fragrance, sound or change of the design in the interior. Another solution to this could be to enable the passengers to perform things in the car that they do normally, when not in a car.

- In order to make people more relaxed - they could listen to the same sound that the baby hear when in the mothers stomach, the sound known to be one of the most relaxing sound in the world. This should, however, not be used by the driver since the relaxation it gives can cause drowsiness and decrease level of performance.

- The driver could receive feedback of driving behavior based on identification of the passengers' facial expressions. There has been recordings and analyzes of driver's facial expressions to identify reactions and emotions during different driving situations. This could be utilized also for passenger's mimic to determine when the passengers are suffering from nausea and perhaps even to determine the pre-stages to nausea and alert the driver of this before the passenger starts feeling affected.

- The use of carbon filter in cars to eliminate odors in the coupé already exists to some extent, but not in all cars. The carbon filters could also be combined with gas detectors that is connected with the air conditioner and shuts off this if the outside air contains large amounts of carbon dioxide, NOx-gases or ammonium. The gas detectors could also be developed to detect sulphur which many also thinks is an unpleasant odor. Sulphur occurs for instance in emissions from paper mills.

Vibrations

- The tires could have embedded shock absorption.

- Wobbling can be minimized with the help of suspensions near the tires In horizontal counteracting direction. This might decrease lateral frequencies (which have impact on motion sickness).

- In order to minimize vibrations on the thighs, a footrest can be used for the passengers. This would minimize the contact area between the thighs and seat and thus decrease transfer of vibrations onto the thighs.

- The backseats could be more similar to the front seats and not be fastened to the undercarriage. The seats could also be fastened to the ceiling with the purpose to minimize vibrations in the backrest.

- *Electric air suspension* is a variant of the traditional spring system and works much like hydraulics but contains air instead of oil. It is described by the supplier *Cotinental* in the following way: "*A piston moves in an aluminum cylinder which is filled with air, as opposed to oil. A part of this air is squeezed out by the piston during the damping process and therefore creates an additional progressive absorption effect. Another part flows through the valves, creating a damping effect.*" (Continental, 2012)

  This dampening function is used to, instead of lowering the frequency, absorb the chock created by texture and bumps in the road surface. The absorption of vibration and shocks would both increase the comfort cue to lowered high frequency vibration and also decrease the occurrence of low frequency vibration and thus reduce the onset of motion sickness.

  The suspension was tested by the authors of this report with the purpose to evaluate if any difference could be felt comparing to other suspensions as a basis for new ideas. The test took place in a Citroen C5 with electric air suspension, on an asphalt road with lots of holes in it.