# Motion sickness in tilting trains

## Description and analysis of the present knowledge

by

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Literature study

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# Preface

This study has been carried out at the Swedish National Road and Transport Research Institute (VTI), Linköping in cooperation with the Royal Institute of Technology (KTH), division of rail vehicles in Stockholm.

This study is part of the research project "Gröna Tåget" (the Green Train).

The financial support from VINNOVA and the Swedish National Rail Administration, Banverket (BV) is acknowledged.

This report covers motion sickness with particular focus on tilting trains.

## Abstract

This report is divided in two main parts. The first part includes chapters 2 and 3 and covers knowledge found in the literature. Chapter 2 gives a selected summary over experiences where motion sickness has been reported together with a characterisation of motions involved that may be the cause of motion sickness for this experience. Chapter 2 also includes experiences from tests performed in laboratories. Chapter 3 reports on different hypothesis of motion sickness as well as the dependence of time.

The second part consists of Chapters 4 and 5. Chapter 4 reports on specific motion quantities for tilting trains and compares motions measured on tilting trains with motions known to cause motion sickness in laboratories. The final chapter discusses and draws conclusions on the findings in the literature and on the analysis made in chapter 4.

Key words: tilting trains, motion sickness, habituation, motion quantities

## Terminology and definitions

| Term | Definition |
|---|---|
| Horizontal | Direction in plane to earth horizon |
| Motion sickness | Sickness caused by motion |
| Nausea | Sensation of unease and discomfort in the stomach |
| Oculomotor | Nerve in the mid brain connected to eye control muscles |
| Otoliths | Vestibular organs sensitive to linear acceleration |
| Proprioceptive | Information of the body posture from sensors located in muscles and joints. |
| Semicircular canals | Vestibular organs sensitive to rotational acceleration |
| Somatic | Here referring to skin, movement control, organs of sight and equilibrium and part of the nervous system related to these parts of the body. |
| Sopite | A symptom-complex centred around "drowsiness" and "mood changes" |
| Tilting train | Train with capability to tilt the carbody, thus reducing the lateral acceleration perceived by the passenger |
| Velocity storage | Brainstem circuits which extends the frequency response from the vestibular nerve to lower frequencies |
| Vestibular organs | Consists of two organs of otoliths sensitive to linear acceleration and three semicircular canals sensitive to rotational acceleration. These organs are located in the inner ear. |

### *Local reference system*

The local reference system for the carbody and relevant parameters is defined through:

Longitudinal, in travelling direction
Lateral, right-oriented to travelling direction
Vertical, perpendicular to floor plane
Roll, rotation around the longitudinal axis of a body
Pitch, rotation around the lateral axis of a body
Yaw, rotation around the vertical axis of a body

## Symbols and abbreviations

| Symbol | Description |
|---|---|
| $a_{wf}(t)$ | Frequency weighted acceleration |
| BV | Banverket (Swedish National Rail Administration) |
| CNS | Central Nervous System |
| FACT | Fast And Comfortable Trains |
| IR | Illness Rating |
| ISO | International Standards Organization |
| JNR | Japanese National Railways |
| $k_{MSDV}$ | Constant in the Motion Sickness Dose Value model |
| $k_{\mathrm{ND}}$ | Constant in the Net Dose model |
| $k_{\mathrm{O}}$ | Constant in Oman's model |
| KTH | Royal Institute of Technology (Stockholm, Sweden) |
| MISC | Misery Scale |
| MSI | Motion Sickness Incidence |
| MSQ | Motion Sickness Questionnaire |
| MSDV | Motion Sickness Dose Value |
| MSDVz | Motion Sickness Dose Value, vertical direction |
| NASA | National Aeronautics and Space Administration |
| NCA | Non-Compensated Acceleration (lateral acceleration in track plane) |
| ND | Net Dose |
| PDI | Pensacola Diagnostic Index |
| PSD | Power Spectral Density |
| r.m.s. | root mean square |
| SMS | Symptoms of Motion Sickness |
| SMSI | Symptoms of Motion Sickness Incidence |
| SSQ | Simulator Sickness Questionnaire |
| TGV | Train á Grande Vitesse |
| TGV-Duplex | Two level TGV train |
| TNO | Human Factor Research Institute (Soesterberg, the Netherlands) |
| VTI | Swedish National Road and Transport Research Institute (Linköping, Sweden) |
| $W_f$ | Function for weighting accelerations in relation motion sickness, developed for vertical direction |
| $W_g$ | Function for weighting accelerations in relation motion sickness, developed for lateral direction |

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# 1 Introduction

## 1.1 *Background to the present study*

Growing competition from other modes of transportation has forced railway companies throughout the world to search for increased performance. Travelling time is the most obvious performance indicator that may be improved by introducing high-speed trains. Trains with capability to tilt the bodies inwards in the curve is a less costly alternative than building new tracks with large curve radii. The tilt inwards reduces the centrifugal force felt by the passengers, allowing the train to pass curves at enhanced speed with maintained ride comfort. Trains capable to tilt the bodies inwards are often called tilting trains.

Tilting has today become a mature technology accepted by most operators, but not favoured by many. In the study *Tilting trains, a description and analysis of the present situation,* [Persson, 2007], motion sickness was identified as one area where research could improve the competitiveness of tilting trains.

The cause of motion sickness is often described by a model. The model can be derived from a theoretical point of view starting from the senses of the human or from tests performed with subjects in a real environment. Laboratory tests come in somewhere in between when researchers try to prove their models with tests under well defined conditions.

The difference between non-tilting and tilting rolling stock has received particular interest as the tilting trains cause more motion sickness than non-tilting trains. This was the base for the EU-funded project *Fast and Comfortable Trains* (FACT). The FACT-project contained three parts; part 1 was related to track layout, part 2 to the onset of motion sickness and part 3 to how to calculate motion sickness based on simulations.

FACT involved on-track tests where the evaluation of some tests showed good correlation between vertical acceleration and motion sickness. However, vertical acceleration was not claimed to be the prime cause of motion sickness.

The correlation between a certain motion and its impact on the onset of motion sickness is important for reducing motion sickness. In particular we are interested in the limited set of variables which can be influenced and controlled in the tilting train itself or by modifications of the track geometry.

Motion sickness is also experienced in other modes of transportation. Motion sickness at sea is the most known, but the knowledge derived at sea can not be applied on trains as the motions differ. The levels of vertical acceleration at sea are proven to cause motion sickness in laboratories, but no single motion can explain the onset of motion sickness in (tilting) trains.

## 1.2 *Objective and approach of the present study*

The objective with the present study is to gather available knowledge on motion sickness by performing a literature study covering motion sickness with particular focus on tilting trains. Reports from other modes of transportation as well as laboratory tests give valuable input and are therefore included.

A second objective has been to analyse the knowledge and to draw conclusions on the onset of motion sickness or at least to recommend continued research.

# 2 Evidence of motion sickness

## 2.1 *Signs and symptoms*

Motion sickness can generally be explained as being dizzy or nauseated caused by a real and/or apparent motion. Some definitions limit the area to motions in vehicles, but is here taken in its wider perspective.

There are many different symptoms of motions sickness mentioned in the literature. Gathering the signs and symptoms in groups may help to understand the overall picture, but the split is not obvious and several different proposals have been given, Table 2-1 shows one possible grouping. The examples in Table 2-1 indicate what type of signs and symptoms that may be expected. The "objective group" is interesting as these signs and symptoms may be used as an objective mean to describe the degree of motion sickness. Descriptions of the human receptors are found in Section 3.1.

***Table 2-1: Example of signs and symptoms of motion sickness in the literature***

| Gastro-related | Somatic | Objective | Emotional |
|---|---|---|---|
| Stomach awareness | Dizziness | Skin humidity | Anxious |
| Nausea | Exhausted | Pulse rate | Nervous |
| Inhibition of gastric motility | Fatigue | Blood pressure | Scared / Afraid |
| Sick | Weak | Body temperature | Tense |
| Queasy | Tired | Respiration rate | Angry |
| Ill | Hot / Warm | | Worried |
| Retching | Sweaty / Cold sweaty | | Sad |
| Vomiting | Lightheaded | | Upset |
| | Shaky | | Confused |
| | Headache (especially frontal) | | Butterflies |
| | Blurred vision | | Panicky |
| | Like dying | | Hopeless |
| | Short winded | | Regret |
| | Yawing | | Apathy |
| | Drowsiness | | Disgusted |
| | Facial pallor | | Gross |
| | Increased salivation | | |
| | Swallowing | | |
| | Malaise | | |

## 2.2 *Motion sickness questionnaires*

### 2.2.1 General

Questionnaires with a selection of signs and symptoms and different scales play an important role to judge the degree of motion sickness. These questionnaires can be divided in "one dimensional well-being scales" or "multi-dimensional symptoms lists". Recent research combines scales with symptoms lists as they have different advantages. An example of motion sickness questionnaire used by FACT is given in Annex A.

### 2.2.2 Symptoms lists

Graybiel, Wood, Miller & Cramer [1968] developed the Pensacola Diagnostic Index (PDI) which is an example of a multi-dimensional symptoms list. Graybiel et al use nausea, skin pallor, cold sweating, increased salivation and drowsiness and call them the *big five* within symptoms. They scale and add the symptoms to a total sickness score. The score is finally transferred to a severity expression ranging from frank sickness to slight malaise.

Kennedy, Lane, Berbaum & Lilienthal [1993] developed a subjective motion sickness scale for motion sickness in simulators called the *Motion Sickness Symptom Checklist* later referred to as the *Motion Sickness Questionnaire* or just MSQ. A more recent development made by Gianaros, Muth, Mordkoff, Levine & Stern [2001] divides descriptions of motion sickness in four categories, Table 2-2. Gianaros et al used a scale from 1 (not at all) to 9 (severe) to rate how accurately the statements in the questionnaire describe the experience of test subjects.

***Table 2-2: The Motion Sickness Assessment Questionnaire,*** *[Gianaros et al, 2001]*

| Descriptor | Gastro-related | Central | Peripheral | Sopite-related |
|---|---|---|---|---|
| Sick to stomach | X | | | |
| Queasy | X | | | |
| Nauseated | X | | | |
| May vomit | X | | | |
| Dizzy | | X | | |
| Spinning | | X | | |
| Faint-like | | X | | |
| Lightheaded | | X | | |
| Disorientated | | X | | |
| Sweaty | | | X | |
| Clammy – Cold sweat | | | X | |
| Hot – Warm | | | X | |
| Annoyed – Irritated | | | | X |
| Drowsy | | | | X |
| Tired – Fatigued | | | | X |
| Uneasy | | | | X |

Kennedy et al [1993] modified the MSQ to the *Simulator Sickness Questionnaire* or just SSQ. The SSQ split the symptoms in three profiles; nausea, oculomotor and disorientation. Some symptoms are placed in two profiles. The degree of each symptom is estimated to a four level scale (0, 1, 2 and 3) where 3 is the highest degree. The points are added for each symptom profile. A total simulator sickness value may be received by, after individual scaling, adding the three profile sums to a grand total, Table 2-3.

***Table 2-3:* *Simulator Sickness Questionnaire,*** *[Kennedy et al, 1993]*

| Symptom | Nausea | Oculomotor | Disorientation |
|---|---|---|---|
| General discomfort | X | X | |
| Fatigue | | X | |
| Headache | | X | |
| Eye strain | | X | |
| Difficulty focusing | | X | X |
| Increased salivation | X | | |
| Sweating | X | | |
| Nausea | X | | X |
| Difficulty concentrating | X | X | |
| Fullness of head | | | X |
| Blurred vision | | X | X |
| Dizzy (eyes open) | | | X |
| Dizzy (eyes closed) | | | X |
| Vertigo | | | X |
| Stomach awareness | X | | |
| Burping | X | | |

Förstberg [2000] thought that the existing well-being scales were too coarse, which forced him to develop the Symptoms of Motion Sickness Incidence (SMSI). The SMSI is the ratio between subjects having selected symptoms and the number of subjects. Förstberg used the symptoms dizziness and nausea from the symptoms lists and the negation of *I feel alright* from the well-being scale. A person having a symptom at start was omitted from the evaluation. I.e. SMSI is the percentage of test subjects that have changed its well being from well to not feeling well or becoming dizzy or nauseated during the test.

### 2.2.3 Well-being scales

Well being scales, also called nausea rating scales, have been particularly used at field tests as they condense information from large data in a convenient way. Lawther and Griffin [1986] developed the *illness rating* (IR) scale; The IR scale is derived from the PDI but transferred to a one-dimensional well-being scale. The original IR-scale had four levels, but Turner [1993] modified the scale to have 5 levels for improved resolution, Table 2-4.

***Table 2-4: Modified illness rating**, [Turner, 1993]*

| Label | Scale |
|---|---|
| I feel alright | 0 |
| I do not feel quite well | 1 |
| I feel rather unwell | 2 |
| I feel bad | 3 |
| I feel very bad | 4 |

The Misery Scale (or simply MISC) developed by TNO Human Factor Research Institute [De Graaf, Bles, Ooms & Douwes, 1992] is an example of an one dimensional well-being scale with many levels, Table 2-5.

***Table 2-5: The Misery Scale**, [De Graaf et al, 1992]*

| Label | Scale |
|---|---|
| No problems | 0 |
| Stuffy or uneasy feeling in head | 1 |
| | 2 |
| Stomach discomfort | 3 |
| | 4 |
| Nauseated | 5 |
| | 6 |
| Very nauseated | 7 |
| | 8 |
| Retching | 9 |
| Vomiting | 10 |

Note that motion sickness scales are of the ordinal type, a scale in which *a higher number corresponds to a higher degree of a given property*. An ordinal scale provides no other information than the order between its items. Numerical differences between the positions on the scale have no particular significance and interpretation of the average is doubtful. Still the average is commonly used.

## 2.3 *Motion sickness reports*

### 2.3.1 General

Evidence of motion sickness has been reported in air, in space, at sea, on cars, on trains, at skating, at fairground rides etc. and there are plenty of examples for most of them. Dobie, McBride, Dobie & May [2001] report on nausea and vomiting caused by motion sickness of 443 children from 9 to 18 years old for 13 different modes of transportation, Figure 2-1 and Figure 2-2. The values given by Dobie et al are average values for US children that have travelled with each mode of transportation, but the number of travelling experiences with trains and cruise ships are significantly lower than for the other modes of transportation.

Note that Dobie et al takes the average over non linear scales which are mathematically doubtful. These figures are here given to show where motion sickness can be expected.

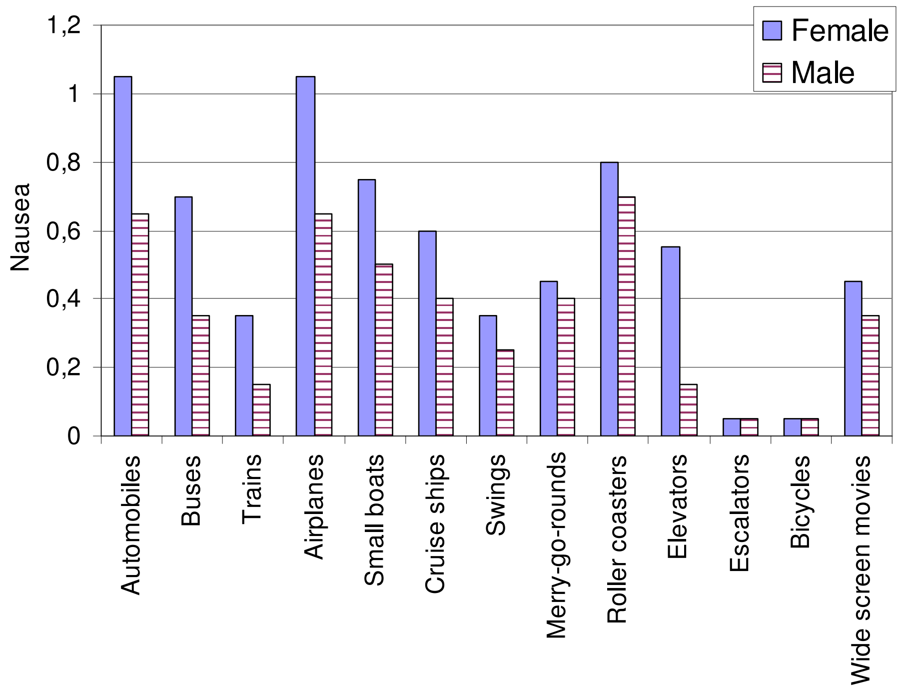


***Figure 2-1: Average nausea experience of 9 to 18 years old children in US,***
*[Dobie et al, 2001], 0 = never, 1 = rarely, 2 = frequently, 3 = always*

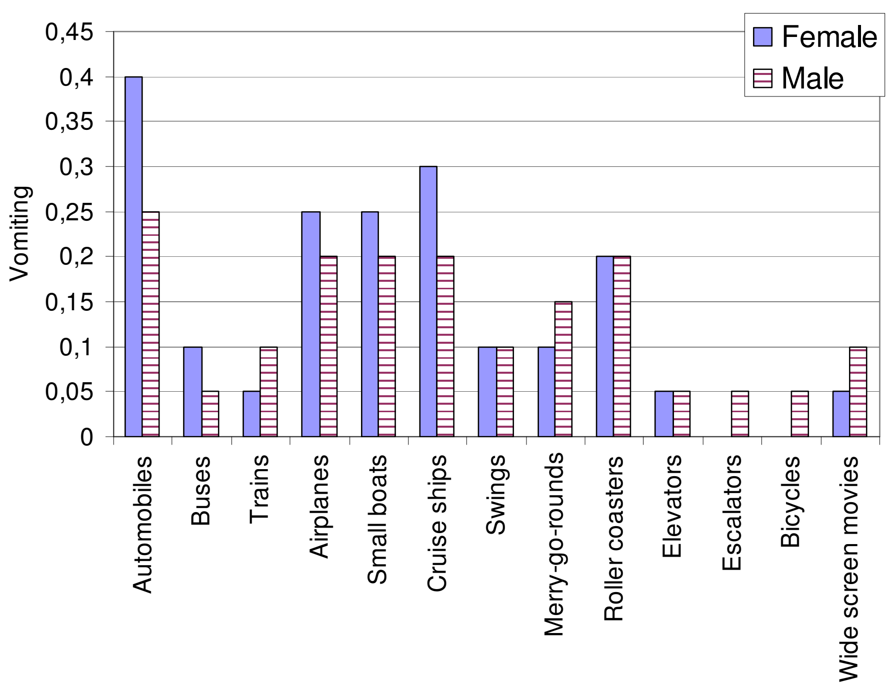


***Figure 2-2: Average vomiting experience of 9 to 18 years old children in US,***
*[Dobie et al, 2001], 0 = never, 1 = rarely, 2 = frequently, 3 = always*

This section gives a selected summary over experiences where motion sickness has been reported together with a characterisation of motions involved that may be the cause of motion sickness for this experience.

### 2.3.2 Air crew

Reports on motion sickness among crews on aircrafts is rare, but has been reported for fighter pilots in education by Hemmingway and Green [1945]. The survey covered 2689 student pilots at US Army Air Force making ten flights each. 11% of the student pilots suffered from motion sickness in at least one flight of the ten flights. The average motion sickness incidence was 2,5%, but the survey are prone to response bias as the outcome could be career-related. In 1945 motion sickness was a reason to disqualifying student fighter pilots. Hemmingway and Green used a 0 (no sickness) to 5 (strong sickness) scale and found a strong reduction in the amount of motion sickness during flight training, Figure 2-3. This adaptation to motion has also been used in desensitization programs within the UK Royal Air Force since 1966 [Bagshaw & Stott, 1985]. The program consists of one ground phase and one flying phase with the aim to improve pilot motion sickness resistance to the demanding motion environment of fast jets.

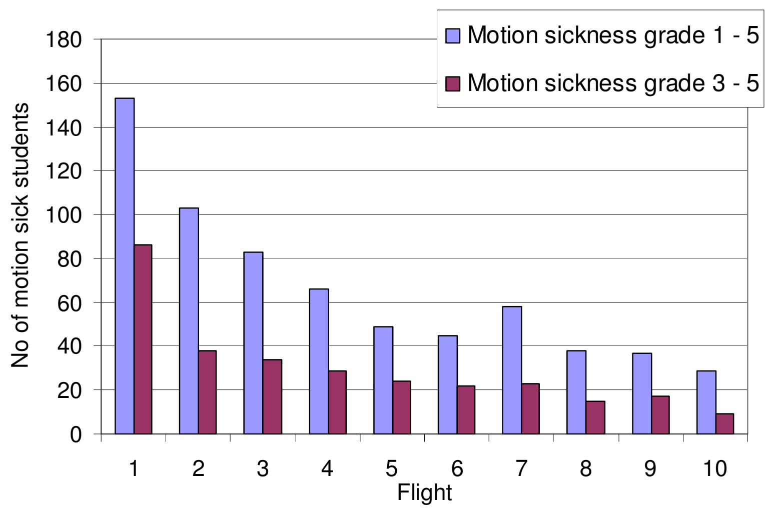


***Figure 2-3: Number of motion sick cases at flight training among 2689 student pilots,*** *[Hemmingway & Green, 1945]*

Nausea is also suspected as the cause of some accidents with aircrafts making high rotational velocities at low altitudes. Air crew with front view experience much less motion sickness than air crew without front view. Benson [1978] state that motion sickness impairs pilot performance like delayed response to instructions.

The motions for fighter pilots is characterised of very high vertical accelerations and high roll velocities at low frequencies. Only crew with front view has correct visual reference. The fighter pilots also receive a large amount of visual information at low altitudes, which may result in a feeling of pitch motion as the eyes tend to follow the ground.

### 2.3.3 Air passengers

Motion sickness among air passengers have been reported by Lederer & Kedera [1954] to 0,5 %, this value was based on 1,1 million passengers. The reported level of incidences was based on aircrafts carrying 21 to 52 passengers, with less level of incidences on the larger aircrafts.

Money [1970] claims that introduction of high-flying jets have reduced the figures given by Lederer & Kedera. Poingt [1996] supports this theory and refers to Air France which only is said to have one occurrence of motion sickness in 1994. These statements are to some degree contradictory to Dobie et al [2001], Figure 2-1 and 2-2, which point out airplanes as one of the modes of transportation with the highest frequency of motion sickness. One critical phase is at start and landing when the aircraft may pass turbulent air layers causing low-frequency motions of the aircraft with the primary disturbance in the vertical direction. At other phases of the flight, the pilot has the possibility to avoid the turbulent areas by selecting another route.

Turner, Griffin, & Holland [2000] claim that air sicknesses today remains a problem for passengers on small aircrafts only. 0,5% of passenger reported vomiting and 8,4% reported motion sickness during short-haul flights on small aircrafts. Turner et al also measured movements and correlated the motions to $MSDV_Z$ with some success, Table 2-6.

***Table 2-6:*** ***Measured acceleration in small planes at short-haul flights,*** *[Turner et al, 2000]*

| Direction | $W_f$-weighted[1)] r.m.s accelerations [m/s$^2$] |
|---|---|
| Longitudinal | 0,02 |
| Lateral | 0,05 |
| Vertical | 0,11 |

1) See Section 2.4.3 for description of the frequency weighting

There are no signs of motion sickness at calm flying conditions; this excludes the theory of self controlled motions in banked (tilted) position as the main cause of motion sickness in aircrafts.

Turner et al found strong correlation between lateral and vertical acceleration which excludes the possibility to, based on measurements in aircraft, judge which direction is the main cause of motion sickness.

### 2.3.4 Space

Motion sickness in space is well known since the first space flights, [Lackner & DiZio, 2006]. They report that 70% of the astronauts in the first space mission have got motion sickness and that incidents are lower for experienced astronauts. Despite training programs for adaptation or habituation, motion sickness is space remains a problem. Benson [1988] reports that approximately 50% of all time space crews have experienced motion sickness. Characteristically, there is a decline in the intensity of symptoms with continued exposure to the atypical force environment and most astronauts have adapted and are symptoms free by the third or forth day. Astronauts receive similar problem when returning to normal gravity environment. Oman [1998] report that no differences are found between men and women and no differences has been noted based on age, although no children or very elderly individuals have flown in space.

Tests during parabolic flights have been used to simulate weightlessness. A modified aircraft is used at these test where the subjects alternating sense zero gravity and about 1,8 g. The subjects perform self controlled motions during the zero gravity periods. Graybiel [1978] reports on such test where the subjects performed pitch and roll movements with their heads. A strong correlation between head movements and motion sickness was found.

The motion in space is characterized of self controlled motions in weightlessness. Missing vertical reference is believed to be a main contributor to motion sickness. Head movements have been identified as the dominant provocative stimulus. Sickness severity has been correlated with average head acceleration by Oman & Shubentsov [1992]. Nauseous astronauts drastically limit their head movements. Pitch and roll motions are most provocative, possibly because the normal change in static otolith organ response does not occur when the head is tilted in weightlessness.

### 2.3.5 Sea

Motion sickness at sea has a long history; Hippocrates (5$^{th}$ century BC) declared that sailing on the sea shows that motion disorders the body, [Reason, 1974]. Chinn [1963] reported that 25 to 30% of sea passengers experience motion sickness the first two to three days at an Atlantic crossing.

Lawther & Griffin [1988] made an extensive passenger survey on ships crossing the English Channel; 7 % reported motion sickness among 20 thousand passengers on 114 voyages on 9 vessels (6 ships, 2 hovercrafts and 1 jetfoil). 21 % of the passengers said they felt "slightly unwell". Females got more motion sick than males and there was a slight decrease in sickness occurrence with increasing age. The motion of the ships was correlated to the consequent motion sickness amongst passengers. Smaller vessels generally show higher acceleration levels and higher dominant frequencies than larger vessels.

Several studies have reported that laying passengers receive less motion sickness than passengers in upright position so also in the passenger survey made by Lawther & Griffin [1988].

Roll stabilizers, which have a capability to reduce roll by 90%, has not proven to reduce motion sickness [Morrison, Dobie, Willems & Endler, 1991]. Roll also shows less good correlation to motion sickness than vertical, longitudinal and pitch accelerations.

The motions at sea are characterised of low frequency vertical, lateral, roll and pitch motions, in most cases, at absence of correct visual reference, Table 2-7.

***Table 2-7: Measured accelerations in the centre of ships at hard weather (7-9 m/s wind) on the English Channel,*** *[Lawther & Griffin, 1986]*

| Direction | Un-weighted r.m.s accelerations [1)] |
|---|---|
| Longitudinal | 0,15 m/s$^2$ (dominant frequency 0,2 Hz) |
| Lateral | 0,42 m/s$^2$ (dominant frequency 0,15 Hz) |
| Vertical | 0,54 m/s$^2$ (dominant frequency 0,2 Hz) |
| Roll | 0,6 deg/s$^2$ (dominant frequency 0,15 Hz) |
| Pitch | 0,9 deg/s$^2$ (dominant frequency 0,2 Hz) |
| Yaw | 0,3 deg/s$^2$ (dominant frequency 0,2 Hz) |

1) Frequency weighting has low influence as the frequency content has a pronounced peak at 0,1 – 0,2 Hz.

Lawther & Griffin [1986] found strong correlation between motion variables, but in particular between vertical, longitudinal and pitch accelerations, which excludes the possibility to, based on measurements in ship, judge which direction is the main cause of motion sickness.

Motion sickness can also be experienced after the sea travel and is then called *Mal de Debarquement*. Gordon, Spitzer, Doweck, Melamed & Shupak [1995] reports that 72% of sea crew members have experienced sickness at disembarkation. Rough sea and prolonged voyage makes the phenomenon stronger. The duration of the phenomenon range from minutes to days, indicating an average recovery time longer than one hour.

### 2.3.6 Road

Dobie et al [2001] pointed out automobiles as one modes of transportation where children have experienced most nausea and motion sickness (vomiting), Figure 2-1 and 2-2. Passengers are much more prone to motion sickness than drivers. Chinn [1963] reports that 3 to 4% get motion sick in cars as passengers. Turner [1993] reports that 10% get nausea and 1 to 2% motion sick (vomiting) in buses as passengers. Turner & Griffin [1999] reports that 13% felt nausea and that 1,7% get motion sickness (vomiting) in a questionnaire study of 3256 coach travellers. Females were reported to be three times as sensitive as males. Motion sickness's sensibility decreases with age and travelling experience. Poor forward visibility was associated with increased sickness. Motion sickness's were more correlated with horizontal movements (fore-and-aft and lateral) than vertical and roll motions.

Atsumi, Tokonaga, Kanamori, Sugawara, Yasuda & Inagaki [2002] developed a model describing motion sickness in cars from tests made in a moving platform simulator. They used vertical, roll and pitch acceleration as input variables to a model describing motion sickness in cars. Longitudinal acceleration is also found important, but is excluded from the model due to strong correlation to driver behaviour. The input variables are evaluated at 0,2 Hz and 0,5 Hz, with approximately 3 times higher sensitivity for 0,2 Hz than for 0,5 Hz. Atsumi et al validated the model with on road tests and claims that the model may be used to design cars with lower risk for motion sickness.

The motion on roads is characterised of roll and lateral motions caused by nominal road geometry and longitudinal motions caused by driver behaviour. Correct visual reference (front view) may be missing depending activity, Table 2-8.

***Table 2-8: Measured accelerations at cross-country bus rides,*** *[Turner, 1992]*

| Direction | $W_f$-weighted[1)] r.m.s acceleration |
|---|---|
| Longitudinal | 0,25 m/s$^2$ (dominant frequency < 0,2 Hz) |
| Lateral | 0,20 m/s$^2$ (dominant frequency < 0,2 Hz) |
| Vertical | 0,05 m/s$^2$ (dominant frequency 1,5 Hz) |
| Roll | 1,7 deg/s$^2$ (dominant frequency 0,8 Hz) |
| Pitch | 0,6 deg/s$^2$ (dominant frequency 1,5 Hz) |
| Yaw | 1,1 deg/s$^2$ (dominant frequency < 0,2 Hz) |

1) See Section 2.4.3 for description of the frequency weighting

Atsumi et al [2002] found a strong correlation between different motions which excluded the possibility to, based on measurements in cars, judge which direction is the main cause of motion sickness.

### 2.3.7 Rail

Reports of motion sickness in non-tilting trains are rare, but have been reported. Kaplan [1964] reported that 0,13% of the passengers get motion sick among 370 thousand passengers on the Baltimore and Ohio Railroad. Kaplan reported more cases of motion sickness for females than for males and more for children than for adults, Figure 2-4.

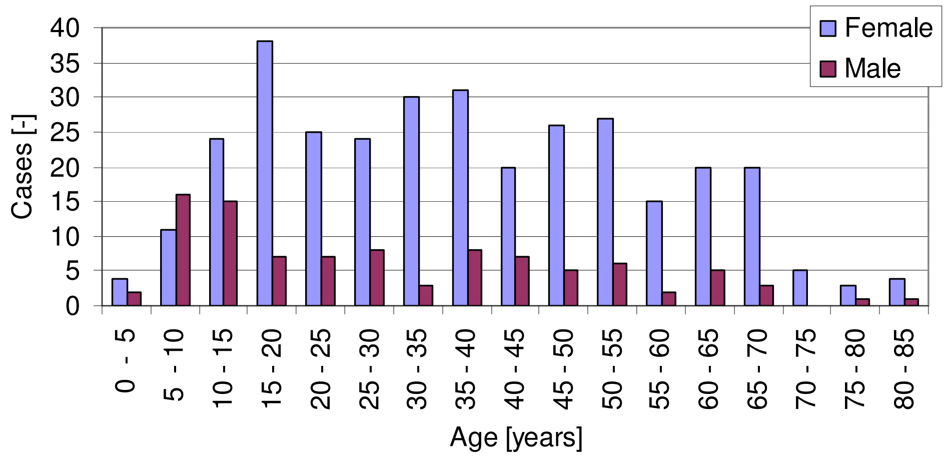


***Figure 2-4: Number of motion sick cases on the Baltimore and Ohio Railroad,***
*[Kaplan, 1964]*

Kaplan also found that susceptible individuals tended to fall ill (become motion sick) within the first four hours of the journey with a marked decrease in cases towards the end of the travel, Figure 2-5.

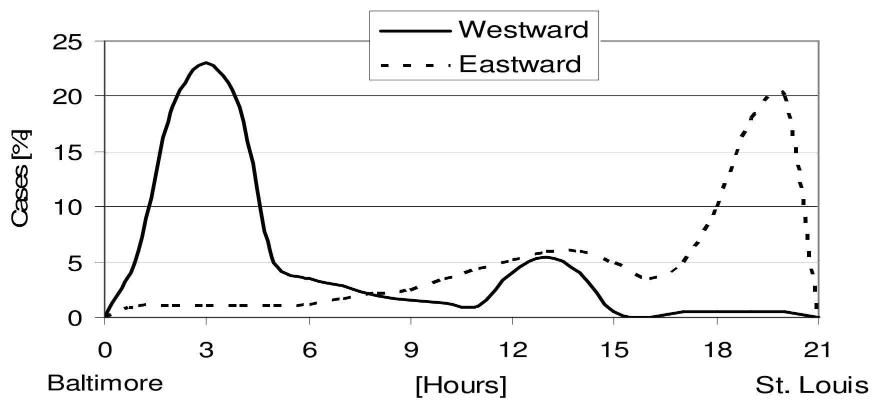


***Figure 2-5: Motion sick case distribution as function of travelled time (100% = all cases),***
*[Kaplan, 1964], the westward trains start in Baltimore and the eastward trains in St. Louis*

Rough terrain (gradients and curves) increased the susceptibility when it coincided with wakening and eating hours. Kaplan found a significant decrease in reported cases during sleeping hours. Kaplan finally point out translational acceleration combined with rotational motion of the head as the prime cause of motion sickness on trains.

Ueno, Ogawa, Nakagiri, Arisawa, Mino, Oyama, Kodera, Taniguchi, Kanazawa, Ohta & Aoyama [1986] reports that 4% of passengers and 10% of conductors experience motion sickness on the JNR class 165 trains in Japan. Bromberger [1996] reports that 2 % of the passengers on the TGV-Duplex trains experiences motion sickness. Evidence of motion sickness in non-tilting trains has also been reported in US by Money [1970] and in UK by Turner [1993].

The motion in non-tilting trains is characterised of lateral, vertical and roll motions caused mainly by nominal track geometry. Correct visual reference (front view) is missing, Table 2-9.

*Table 2-9:* ***Measured accelerations on trains in Norway on the track section between Kristiansand and Vegårdshei which contains numerous of curves with approximately 300 meter radii,*** *see Section 4.2 for details*

| Direction (rel. carbody) | Frequency weighted[1)] r.m.s accelerations | | Dominant frequency |
|---|---|---|---|
| | non-tilting | tilting | |
| Longitudinal | 0,03 | 0,04 | < 0,1 Hz |
| Lateral | 0,45 | 0,35 | < 0,1 Hz |
| Vertical | 0,04 | 0,07 | < 0,1 Hz |
| Roll | 0,01 | 0,02 | ≈ 0,1 Hz |
| Pitch | 0,001 | 0,002 | None |
| Yaw | 0,01 | 0,01 | ≈ 0,1 Hz |

1) Frequency weighing $W_f$ is applied on all motions except lateral where $W_g$ is used. See Sections 2.4.2 and 2.4.3 for description of the frequency weighting.

Evidence of motion sickness in tilting trains has been reported in Japan by Ueno et al [1986], in Sweden by Förstberg [1996], in Switzerland by Hughes [1997] and in France by Gautier [1999]. Ueno et al reports as high as 26% of the passengers and 32% of the guards experience motion sickness on the passively tilted train JNR class 381. Förstberg [1996] reports 6% motion sickness at a test on X2000 in Sweden and 8 – 15% motion sickness in a test involving different tilt control strategies, Förstberg [2000]. Tilting trains generally show more motion sickness than non-tilting trains. However, the speed of the tilting trains was higher than for the non-tilting trains in reports where both types were considered. Bromberger [1996] state that there is more reported motion sickness's in passively tilted trains than in actively tilted trains.

Donohew & Griffin [2007] report from tests made in France on a tilted version of TGV where they found significantly more motion sickness on morning runs than on afternoon runs independent of test case, Figure 2-6.

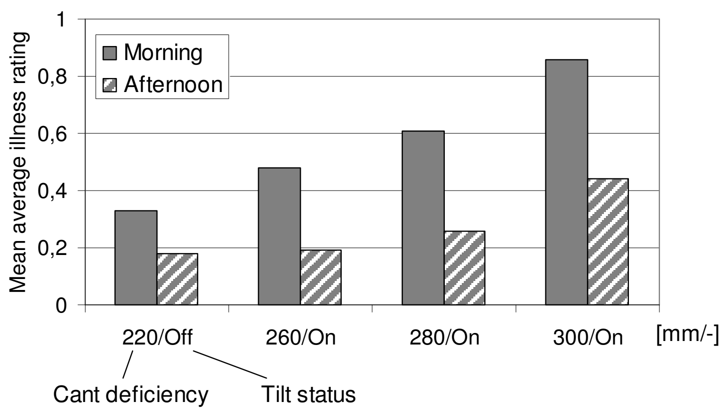


***Figure 2-6: Mean average illness rating for morning and afternoon runs,*** *[Donohew & Griffin 2007]*

Förstberg [2000] and Förstberg, Thorslund & Persson [2005] reports females being 2 to 3 times as susceptible for motion sickness as men in tilting trains. Females are also reported to have sensitivity for travelling direction, backwards giving significantly less motion sickness.

The motion in tilting trains is characterised of lateral, vertical and roll motions mainly caused by nominal track geometry and vertical and roll motions caused by the tilt. Correct visual reference (front view) is missing, Table 2-9.

### 2.3.8 Simulators

Motion sickness in simulators has been acknowledged as a problem since 1950s when helicopter pilots became sick during training in flight simulators, [Casali & Frank, 1986]. The motion sicknesses become a restriction to meet the purpose with the training. Motion sickness is also reported for conditions involving visual stimuli only, like in Cinerama and simulators without motions. Some researchers claim that motion sickness is not the correct term as there is no motion involved. However, the individuals perceive the situation as real motions, and sickness can therefore be considered as motion sickness. Delorme & Marin-Lamellet [1999], report that only 50% of the test subjects could fulfil a drive in a car simulator without motion platform (pure visual information). Some researchers have also compared the degree of motion sickness in simulators with and without motion platform. Drexler, Kennedy & Compton [2004] come to the conclusion that simulators without motion platform give more motion sickness than simulators with motion platform. However there are examples on the opposite, such as Kennedy, Berbaum & Lilienthal [1997].

The content of the scenarios is reported to be important for the degree of motion sickness. Scenarios for car simulators with more curves and more accelerations and brakes tend to give more motion sickness. Zaychik & Cardullo [2005] have investigated the influence of delay between control and the experience feedback. They have made their tests in a car simulator without moving platform, where they delayed the monitor information from up to 165 ms. Zaychik & Cardullo could not prove any difference between different delays.

It should be noted that even the best simulator has limitations when it comes to possible displacement. One typical example is at curving when most simulators introduce lateral force by tilting the body instead of accelerating the body laterally which would have resulted in large lateral movements. However, tilting the body to achieve a lateral force produces a roll motion which is not present in the real case.

## 2.4 *Motion sickness in laboratories*

Motion sickness as result of provocative experiments in laboratories is one very important key in finding the cause of motion sickness as the provocative sensations in laboratories may be simplified compared with the real environment. The main interest here is whole-body oscillations, but also tests with head movements contribute to the knowledge. It is important to note under what conditions each test is made, in particular if support to upper body and/or head is provided.

### 2.4.1 Longitudinal motions

Golding, Müller & Gresty [1999] summarize laboratory test performed with pure longitudinal motions. The test subjects were seated in an upright position oscillating back and forth at frequencies between 0,1 Hz and 1,0 Hz. Golding et al used seats with high backrests and instructed the subjects to keep the head against the headrest providing some support of the tests subjects' upper body and head. The amplitudes were altered from 0,19 to 3,98 m/s$^2$, and they found a sensitivity peak at 0,2 Hz indicating a similar weighting function as in vertical direction, Figure 2-8, may be useful. Griffin & Mills [2002] have shown that there is no significant difference between longitudinal and lateral motion sickness sensitivity at frequencies between 0,2 Hz and 0,8 Hz. The result was based on laboratory tests with pure longitudinal and pure lateral motions. The test subjects were seated in an upright position oscillating back and forth and side to side.

### 2.4.2 Lateral motions

Donohew & Griffin [2004b] proposed a different weighting function in lateral direction than used in vertical. The result was based on laboratory tests with pure lateral motions. The test subjects were seated in an upright position oscillating side to side at frequencies between 0,0315 Hz and 0,8 Hz. The backrest on the chair was low giving little support to the upper body and no support to the head of the test subject. 30% of the test subjects report motion sickness at a frequency of 0,125 Hz and an amplitude of 0,56 $m/s^2$ after half hour of exposure. Mild nausea incidence was used as a base. The weighting function in lateral direction has the greatest sensibility between 0,02 Hz – 0,25 Hz and is in this paper called $W_g$, Figure 2-7.

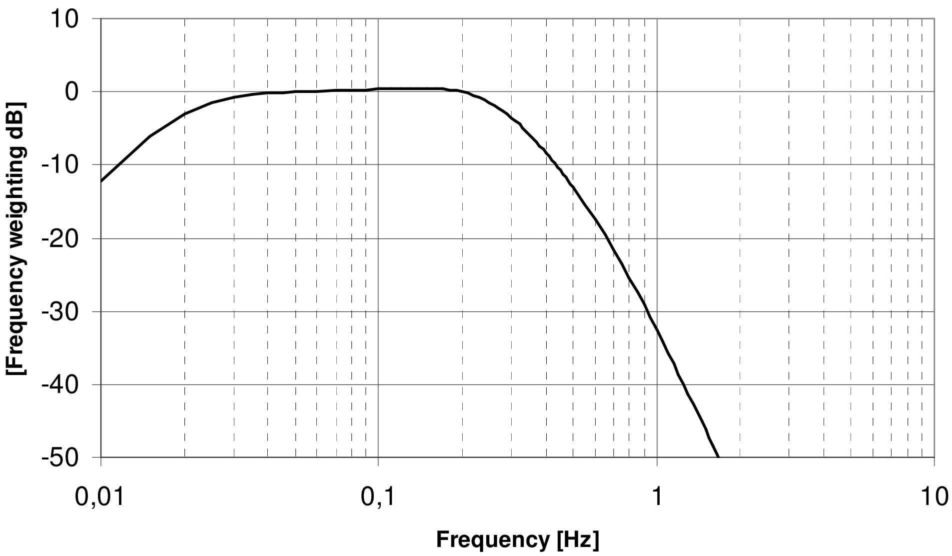


***Figure 2-7: Normalized weighting function, $W_g$, for pure lateral acceleration,***
*[Donohew & Griffin, 2004b]*

### 2.4.3 Vertical motions

O'Hanlon & McCauley [1973] made comprehensive tests in vertical direction with seated subjects. O'Hanlon & McCauley used aircraft seats and instructed the subjects to keep the head against the headrest providing some support of the tests subjects' upper body and head. 50% of the test subjects report motion sickness at a frequency of 0,1 Hz and an amplitude of 0,30 $m/s^2$ r.m.s. 25% of the test subjects report motion sickness at a frequency of 0,1 Hz and an amplitude of 0,16 $m/s^2$ r.m.s. after two hours of exposure. O'Hanlon & McCauley derived a relationship of Motion Sickness Incidence (vomiting) to motion frequency and amplitude. This relationship become the base for the well established weighting function, $W_f$, for pure vertical acceleration causing motion sickness, documented by ISO [1997]. The weighting function has the greatest sensibility between 0,1 and 0,25 Hz, Figure 2-8. The function is primarily applicable to standing or seated passengers exposed by motions in ships and other sea vessels. However, it has been used in other applications and even in other directions.

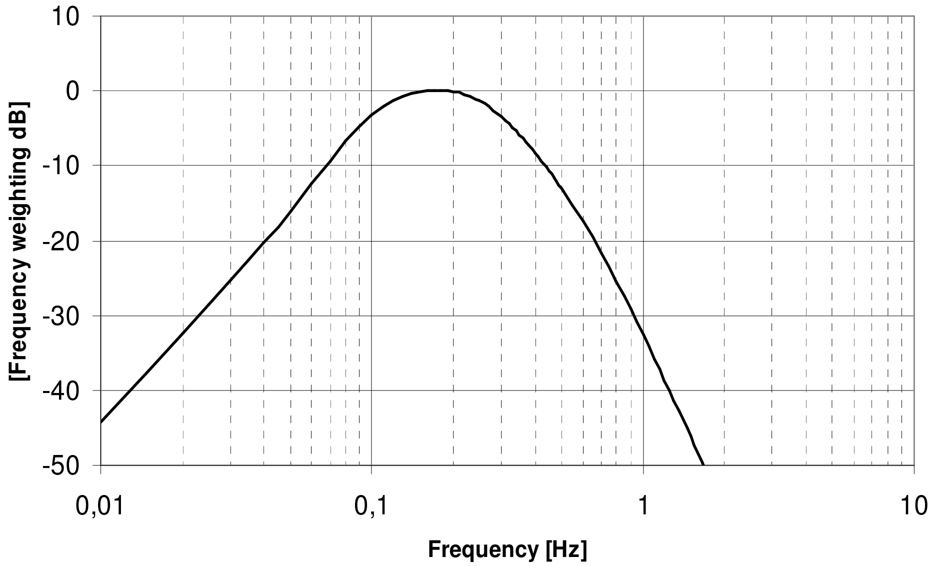


***Figure 2-8: Normalized weighting function, $W_f$, for pure vertical acceleration**, [ISO, 1997]*

### 2.4.4 Roll motions

McCauley, Royal, Wylie, Hanlon & Mackie [1976] has in laboratory tests shown that pure roll at 0,345 Hz does not give motion sickness at an amplitude of 7 degrees. They used aircraft seats and instructed the subjects to keep the head against the headrest providing some support of the tests subjects' upper body and head. The pure roll case was a reference case then McCauley et al combined roll with vertical acceleration, Table 2-11. Wertheim, Wientjes, Bles & Bos [1995] made similar tests but at 0,07 Hz and at an amplitude of 14 degrees and found that roll combined with vertical acceleration does provoke motion sickness. Wertheim et al do not provide any description of the seat, but they instructed the subjects to sit straight which indicates that head support was not provided. Förstberg [2000] has in laboratory tests shown that pure roll at 0,167 Hz does not give motion sickness at an amplitude of 4,8 degrees. The pure roll case was one of several cases Förstberg made with tilting trains in focus, Table 2-13.

Howarth [1999] report from in laboratory tests with pure roll at frequencies ranging from 0,025 Hz to 0,40 Hz, at an amplitude of 8 degrees. The backrest on the chair was low giving little support to the upper body and no support to the head of the test subject. Howarth found no difference in the sickness produced by the different frequencies, but all differed from the static reference case. Howarth concluded that pure roll motion may provoke some motion sickness, but differs from translation motions by its dependence to displacement instead of acceleration.

### 2.4.5 Pitch motions

McCauley et al [1976] has in laboratory tests showed that pure pitch at 0,345 Hz give motion sickness to 9% of the test subjects at amplitude of 7 degrees. They used aircraft seats and instructed the subjects to keep the head against the headrest providing some support of the tests subjects' upper body and head. The pure pitch case was a reference case then McCauley et al combined pitch with vertical acceleration, Table 2-11. They concluded that pure pitch motion is not the prime cause of motion sickness on sea.

### 2.4.6 Yaw motions

There are ample examples of tests that use constant yaw velocity (typically rotation around an Earth-vertical axle) combined with at least one other motion. Many of these tests use the pure yaw motion as reference case like Eyeson-Annan, Peterken, Brown & Atchison [1996]. Constant yaw velocity does not provoke motion sickness.

Guedry, Benson & Moore [1982] used yaw oscillation, they found that 0,02 Hz at 155 degrees per second peak velocity provoke motion sickness, but not 2,5 Hz at 20 degrees per second peak velocity, when the subjects at the same time try to find a certain value in a head fix matrix display. Guedry et al do not provide any description of the seat. It should be noted that the used conditions are far from what is usual on trains.

Bubka, Bonato, Urmey & Mycewicz [2006] compared constant yaw velocity at 30 and 60 degrees per second with changing yaw velocity between 30 and 60 degrees per second and found that changing yaw velocity cause more nausea than constant yaw velocity. The subject's head was immobilized in the centre of a drum that rotated on an Earth-vertical axis.

### 2.4.7 Combined motions

A test with combined motions generally involves two motions, these tests may be divided in two groups depending on if both motions are changing or just one is changing. The tests with combined motions are summarized in Table 2-10.

***Table 2-10: Summary of combined tests***

| | Roll | Pitch | Yaw (constant) |
|---|---|---|---|
| Longitudinal | | Golding et al [2003] | |
| Lateral | Förstberg [2000]<br>Donohew & Griffin [2004a] | Golding et al [2003] | |
| Vertical | McCauley et al [1976]<br>Wertheim et al [1995]<br>Dahlman [2007] | McCauley et al [1976]<br>Wertheim et al [1995] | |
| Roll | | Wertheim et al [1995] | Purkinje [1820]<br>Eyeson-Annan et al [1996]<br>De Graaf et al [1998] |
| Pitch | | | Purkinje [1820] |

Early combined motion tests involved just one changing variable like Purkinje [1820], who used constant yaw velocity combined with roll or pitch movements to provoke motion sickness. This combination of motions was also the base to Cox’s chair developed to treat mentally ill persons by provoking nausea. One such chair can be seen in Vadstena hospital museum (Sweden).

McCauley et al [1976] combined pitch or roll with vertical motions, Table 2-12. They used aircraft seats and instructed the subjects to keep the head against the headrest providing some support of the tests subjects' upper body and head. The number of subjects participating in each case was 20 or more. McCauley et al also made reference tests with pitch only, vertical only and roll only, Table 2-11.

***Table 2-11: Vomiting incidence in percent, single motion cases,*** *McCauley et al [1976]*

| Frequency [Hz] | Pitch velocity (r.m.s) 33,3 [deg/s] | Vertical acceleration (r.m.s) 1,1 [m/s$^2$] | Roll velocity (r.m.s) 33,3 [deg/s] |
|---|---|---|---|
| 0,250 [1)] | | 31% | |
| 0,345 | 9% | | 0% |

*1) It is unclear why the frequency in the reference cases differs from the combined cases*

***Table 2-12: Vomiting incidence in percent, vertical acceleration with 1,1 m/s$^2$ (r.m.s) at 0,23 Hz combined with pitch or roll velocity,*** *McCauley et al [1976].*

| Frequency | Pitch velocity (r.m.s) [deg/s] | | | Roll velocity (r.m.s) [deg/s] | | |
|---|---|---|---|---|---|---|
| [Hz] | 5,51 | 16,7 | 33,3 | 5,51 | 16,7 | 33,3 |
| 0,115 | 36% | | | 14% | | |
| 0,230 | 40% | 40% | | 43% | 40% | |
| 0,345 | 24% | 25% | 38% | 35% | 8% [1)] | 48% |

1) McCauley et al realized that this value deviated form the other results, but could not give any other explanation than it was due to chance variation.

McCauley et al come to the conclusion that vertical motion alone can provoke sickness and that combination with pitch or roll does not significantly increase the incidence of sickness. It should be noted that the number of subjects were low resulting in a large statistical uncertainty, so McCauley et al could not prove the difference in vomiting incidence between vertical only and vertical combined with pitch or roll to be statistically significant.

Wertheim et al [1995] combined pitch motions of 0,08 Hz to 0,13 Hz with roll motions with the same frequency. The amplitude was 11 degrees in both directions. This combination of movements gave significantly more motion sickness than pure roll. Wertheim et al also combined roll and pitch motions with vertical acceleration with even higher degrees of motion sickness than the motion without vertical acceleration. This conclusion is in contrast to McCauley et al [1976] results. The difference could possibly be explained by the head support provided by McCauley et al.

Dahlman [2007] combined vertical acceleration with roll motions in a test with sea sickness in focus. He found that the case with combined motions gave significantly more motion sickness than cases with pure vertical acceleration and pure roll motion. Dahlman was using car type seats with high backrests so the test subjects had some support of the movement of their upper body.

Förstberg [2000] combined horizontal acceleration with roll in a test with tilting trains in focus. The horizontal acceleration was more or less compensated by the roll motion. Förstberg used 0,167 Hz oscillations with shapes and amplitudes simulating trains passing curves. Also, typical lateral and vertical high-frequency vibrations found in trains were added. The backrest on the chair was high so the test subjects had some support of the movement of their upper body, Figure 2-9.

***Figure 2-9: Interior view of cabin with test subject**, [Förstberg, 2000]*

The exposure time was 30 minutes. Förstberg used a motion sickness rating scale where 0 is no motion sickness and 4 is strong motion sickness (but no retching or vomiting). A result summary is given in Table 2-13.

***Table 2-13: Average motion sickness rating at combined motions,** [Förstberg, 2000], the value in parenthesis gives the ratio of the horizontal acceleration compensated by roll.*

| Horizontal acceleration (peak) [$m/s^2$] | Roll angle (peak) [deg] | | | |
|---|---|---|---|---|
| | 0 | 3,6 | 4,8 | 6,4 |
| 0 | | | 0,19<br>(-) | |
| 0,8 | | 0,42<br>(75%) | 0,89<br>(100%) | |
| 1,1 | 0,64<br>(0%) | 0,68<br>(55%) | 1,13<br>(75%) | 1,34<br>(100%) |

Förstberg came to the conclusion that roll motions alone do not provoke motion sickness, but roll motions does increase the incidence of sickness when combined with lateral motions.

Donohew & Griffin [2004a] combined horizontal acceleration with roll in a test with tilting trains in focus. They used the same motion sickness rating as Förstberg and the exposure time was also the same, 30 minutes. The ratio of the horizontal acceleration compensated by roll was always 100% when roll applied. The backrest on the chair was low giving little support to the upper body and no support to the head of the test subject. The result as function of frequency and amplitude is shown in Figure 2-10.

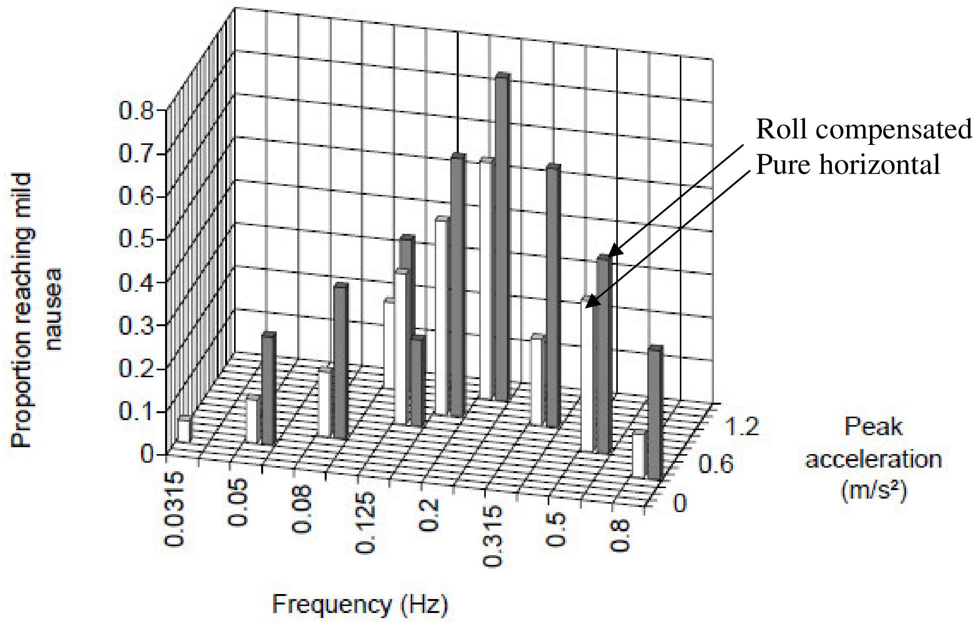


***Figure 2-10: The effect of roll compensated horizontal acceleration**, [Donohew & Griffin 2004a], (white = pure horizontal, grey = roll compensated) as proportion reaching mild nausea*

Donohew & Griffin [2004a] come to the conclusion that roll motions increase the incidence of sickness when combined with lateral motions, particularly at frequencies above 0,2 Hz.

Golding, Bles, Bos, Haynes & Gresty [2003] combined pitch movements with longitudinal and lateral motions. They found longitudinal and lateral motions equal to cause motion sickness when combined with pitch movements. Golding et al used a frequency of approximately 0,2 Hz and amplitudes from 2,0 to 3,1 $m/s^2$. They used seats with high backrests and instructed the subjects to keep the head against the headrest providing some support of the tests subjects' upper body and head.

Eyeson-Annan et al [1996] combined yaw rotation with roll motions and found them to cause motion sickness; pure yaw rotation did not cause any motion sickness. However, no motion sickness was observed as long as the test subject has correct visual reference. De Graaf, Bles & Bos [1998] combined yaw rotation at 180 degrees per second with visual roll stimuli at 30 degrees per second without any signs of motion sickness. The used conditions are far from what is usual on trains, but even at these high amplitudes, yaw combined with roll motion does not cause motion sickness.

### 2.4.8 Posture

Manning & Stewart [1949] studied the effect of posture in a test based on swing motion and a large group of subjects, Table 2-14. Manning & Stewart used seats with backrests providing some support of the tests subjects' upper body. They found that laying passengers received much less motion sickness than seated subjects.

Golding & Kerguelen [1992] studied the effect of posture by comparing vertical motion for sitting subjects with horizontal motion for laying subjects, which give the same information to the organs of equilibrium. The laying subjects received much less motion sickness and

Golding & Kerguelen came to the conclusion that the direction of the motion in relation to gravity is important.

***Table 2-14: The effect of posture and visual reference,*** *[Manning & Stewart, 1949]*

| Attitude of subject | Percent vomiting in less than 30 minutes | | |
|---|---|---|---|
| | External reference | No reference | Internal reference |
| Laying | 5 | 11 | No data |
| Sitting | 28 | 51 | 64 |

Golding, Markey & Stott [1995] compared pure longitudinal motion with seated subjects with laying test subjects exposed with pure vertical motion, which give the same information to the vestibular organs. The laying subjects received much less motion sickness and also Golding came to the conclusion that the direction of the motion in relation to gravity is important.

### 2.4.9 Visual reference

Manning & Stewart [1949] studied the effect of visual reference in the same test as the studied the effect of posture, Table 2-13. They found that subjects without reference received much more motion sickness than subjects with external reference and that internal reference was more provocative than both external reference and the case without reference.

Howarth, Martino & Griffin [1999] studied the effect of visual scene on motion sickness caused by lateral oscillation. They found that external reference has significant beneficial effect, producing less motion sickness than an internal reference. However, the external view must be distant to get the positive effect.

### 2.4.10 Head movements

The movement of the head relative to the body has received interest in several research reports referred in this report. Kaplan [1964] pointed out translational acceleration combined with rotational motion of the head as the prime cause of motion sickness on trains. Most researchers try to control the relative motion by offering head support, but there are also examples where the relative motion is part of the manipulation in the experiment.

Tests during parabolic flights have been used to simulate weightlessness. The subjects perform self controlled motions during the zero gravity periods. Graybiel [1978] reports on such test where the subjects performed pitch and roll movements with their heads. A strong correlation between head movements and motion sickness was found.

Bles, de Graaf & Krol [1995] made tests at enhanced gravity. Three times normal gravity was achieved by a human centrifuge. The subjects performed self controlled head motions resulting in motion sickness. Typically the centrifuge run with constant yaw velocity and it was found that head motions in pitch and roll provoke motion sickness but not head motions in yaw. They concluded that head motions in the same direction as the centrifuge run caused no motion sickness, but head movements in other directions provoke motion sickness.

Also NASA has acknowledged the importance of head movements. The designers of the real-life International Space Station and the Space Shuttle have used different methods to establish a common sense of "up". For example, all of the modules have a consistent "up"-orientation, and the writing on the walls points in the same direction, NASA [2001]. Astronauts are also advised to limit their head movements and to keep in the "up"-orientated direction when symptomatic.

## 2.5 *Summary*

Questionnaires can be divided in "one dimensional well-being scales" or "multi-dimensional symptoms lists". Graybiel et al [1968] developed the Pensacola Diagnostic Index (PDI) which is an example of a multi-dimensional symptoms list. Graybiel et al use nausea, skin pallor, cold sweating, increased salivation and drowsiness and call them the *big five* within symptoms. Well being scales, also called nausea rating scales, have been particularly used at field tests as they condense information from large data in a convenient way. Lawther and Griffin [1986] developed the *illness rating* (IR) scale; The IR scale is derived from the PDI but transferred to a one-dimensional well-being scale. The original IR-scale had four levels, but Turner [1993] modified the scale to have 5 levels for improved resolution.

Evidence of motion sickness has been reported in air, in space, at sea, on cars, on trains, at skating, at fairground rides etc. and there are plenty of examples for most of them. Reports of motion sickness in non-tilting trains are rare, but have been reported. Kaplan [1964] reported that 0,13% of the passengers get motion sick among 370 thousand passengers on the Baltimore and Ohio Railroad. There are several reports of motion sickness in tilting trains and the share of the passengers get motion sick is also higher. One extreme is Ueno et al [1996] reporting as high as 26% of the passengers experience motion sickness on the passively tilted train JNR class 381.

Motion sickness as result of provocative experiments in laboratories is one very important key in finding the cause of motion sickness as the provocative sensations in laboratories may be simplified compared with the real environment. O'Hanlon & McCauley [1973] made comprehensive tests in vertical direction with seated subjects. They derived a relationship of Motion Sickness Incidence (vomiting) to motion frequency and amplitude. This relationship become the base for the well established weighting function, $W_f$, for pure vertical acceleration causing motion sickness, documented by ISO [1997]. Donohew & Griffin [2004b] proposed a weighting function for lateral direction. This weighting function differs from the vertical by higher sensitivity for lower frequencies. Rotations have received much less attention than the translations, and the laboratory tests performed have been performed at significantly higher magnitudes than existing on trains. Many tests have been made with combinations of motions as combinations are known to be very effective in provoking motion sickness.

The movement of the head relative to the body has received interest in several research reports referred in this report. Bles et al [1995] made tests at enhanced gravity. Three times normal gravity was achieved by a human centrifuge. The subjects performed self controlled head motions resulting in motion sickness. Typically the centrifuge run with constant yaw velocity and it was found that head motions in pitch and roll provoked motion sickness but not head motions in yaw. They concluded that head motions in the same direction as the centrifuge run caused no motion sickness, but head movements in other directions provoke motion sickness.

# 3 Hypothesis of motion sickness

## 3.1 *Human receptors*

The human body can receive information about posture and movements by:

1. Sensory information, from the inner ear,
2. Visual information, from the eyes,
3. Proprioceptive information, from muscles.

The sensory information is sensitive for translational and rotational accelerations. The information of translational acceleration comes from the otolith organs and rotational acceleration from the semicircular canals. The response for a sustained motion (constant velocity) will fade out with a time constant of approximately 15 seconds, which corresponds to a cut-off frequency of approximately 0,025 Hz.

The visual information is sensitive for position which may be derivated to velocity. The visual information has an upper frequency limit of approximately 5 Hz.

The proprioceptive information comes from muscles and is sensitive for force, which combined with the vestibular information is sensitive for accelerations with an upper frequency limit of approximately 5 Hz, [Förstberg & Ledin, 1996].

The central nervous system summarizes the information from the receptors to posture and movements.

## 3.2 *The conflict theory*

The sensory conflict is the most common explanation of motion sickness. The different sensitive capabilities of different motion information sources give a sensory conflict, like;

- a passenger sitting in a moving train and looking inside train feels the movements but can not see any,
- a subject in a simulator without moving platform sees movements on displays, but can not feel any,
- a passenger, sitting in a turning aircraft, and makes head movement feels the turning of the aircraft but can not see any.

The theory has developed over the years from Claremont [1931] and Reason & Brand [1975] to today being able to explain most motion sickness cases. Benson [1988] has included the central nervous system and expresses the conflict as:

- *That in all situations where motion sickness is provoked, there is a sensory conflict not only between signals from the eyes, vestibular organs and other receptors susceptible to motion, but also that these signals are in conflict with what is expected by the central nervous system.*

One model of the conflict theory is shown in Figure 3-1.

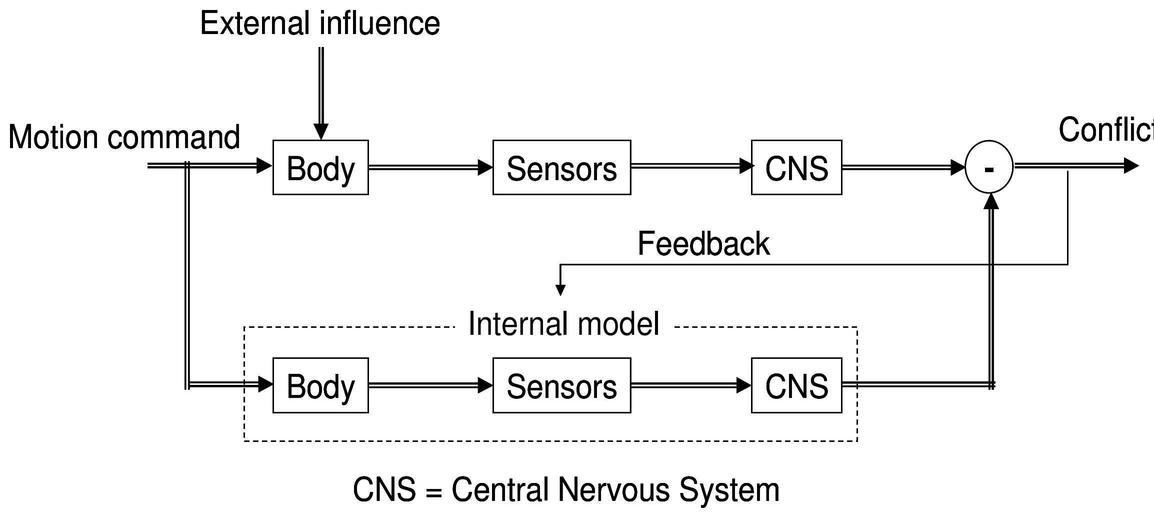


***Figure 3-1: Model of the conflict theory,*** *modified from Bles, Bos and Kruit [2000]*

The model of the conflict theory consists of two paths, the top path represents the actual information from the sensors processed by the Central Nervous System (CNS), and the lower path represents the internal model, which estimate the effect of a given motion command (active motions). The estimated and the actual information are compared, and a conflict signal will be generated if they differ. Passive motions (without motion command) are in the model represented by external influence; these can by them selves create conflict as the external do not have any direct flow to the internal model. Habituation is represented by the feedback from conflict to updating the internal model.

The vestibular system plays a role in motion sickness, since humans with defect vestibular function are immune to stimuli that normally cause motion sickness, i.e. there is no sensory conflict. This includes cases where the stimuli are purely visual.

Some researchers have claimed that the Coriolis cross-coupling may be reason for the conflict, but others claim that the Coriolis force is too small to be the cause. A more likely scenario is that rotations in two directions cause a believed rotation around the third axis by exciting the sensors in the inner ear and activating the velocity storage mechanism. The latter scenario is suggesting that the velocity storage mechanism is important for the production of motion sickness. This theory is supported recent studies, DiZio and Lackner [1991], Bos, Bles & de Graaf [2002] and Dai, Kunin, Raphan & Cohen [2003].

The conflict can also be described by the difference between the sensed direction and the expected direction of vertical. The conflict is by Bles, Bos, de Graaf, Groen & Wertheim [1998] described as:

> *Situations which provoke motion sickness are characterized by a condition in which the sensed vertical as determined on the basis of integrated information from eyes, the vestibular system and the non-vestibular proprioceptors is at variance with the subjective vertical as expected from the previous experience.*

The conflict theory described as difference between the sensed direction and the expected direction of the g-vector is verified by comparing the frequency/amplitude response to test results derived by O'Hanlon and McCauley [1973]. This description is in line with Kaplan [1964] who pointed out translational acceleration combined with rotational motion of the head as the prime cause of motion sickness on trains.

Bubka and Bonato [2003], Bonato and Bubka [2005] and Bubka et al [2006] argue that the variance between the subjective vertical and the real vertical as described by Bos & Bles [1998, 2004] can not explain the result in a Bonato and Bubka's tests, where stand-still test subjects surrounded by a rotation drum with vertical stripes received motion sickness at head pitch movement. Bonato and Bubka explain that there is no variance between the subjective vertical and the real in this experiment, so the theory proposed by Bos and Bles can not be correct. Bonato and Bubka conclude that only the pure sensory conflict theory can explain their findings.

## 3.3 *Competing theories*

Most researchers have today accepted the sensory conflict theory, but there are also competing theories;

*The over-stimulation theory*
The over-stimulation theory is based on over-stimulation of sensors rather than conflict between different sensors. Supporters of the theory give examples where no conflict is involved like low-flying fighter aircrafts where the only input comes from the vision. According to this theory a large amount of signal information is transferred from sensors to the central nervous system. The information is treated as poison and a defence mechanism is triggered.

*The ecological theory*
Riccio & Stoffregen [1991] proposed the ecological theory of motion sickness. Riccio & Stoffregen claim that no sensory conflict exists and suggests that motion sickness is caused by postural instability associated with environmental situations that destabilize the postural control system. Supporters of the theory give examples where conflicts are involved without causing motion sickness. Low frequencies have a destabilizing effect but not high frequencies as these are filtered out by the human body inertia. Low-frequency vibration is claimed to be the prime cause of motion sickness due to its relation to destabilizing the postural control system. Instability persists until a new pattern is learned.

## 3.4 *Time dependence of motion sickness*

Oman [1990] set up a mathematical model of time dependence of motion sickness based on the conflict theory. This model starts with the conflict signal and ends with the magnitude of motion sickness. Oman's model have two paths with two different time constants, one fast path with time constant less or equal to 60 seconds and one slow path with 600 seconds time constant, Figure 3-2. The time constant is a measure on how fast the output responds to a change on input. At high levels a single conflict stimulus produces a virtually instantaneous increment in motion sickness. Observe that the output from the slow path controls the amplification of the fast path.

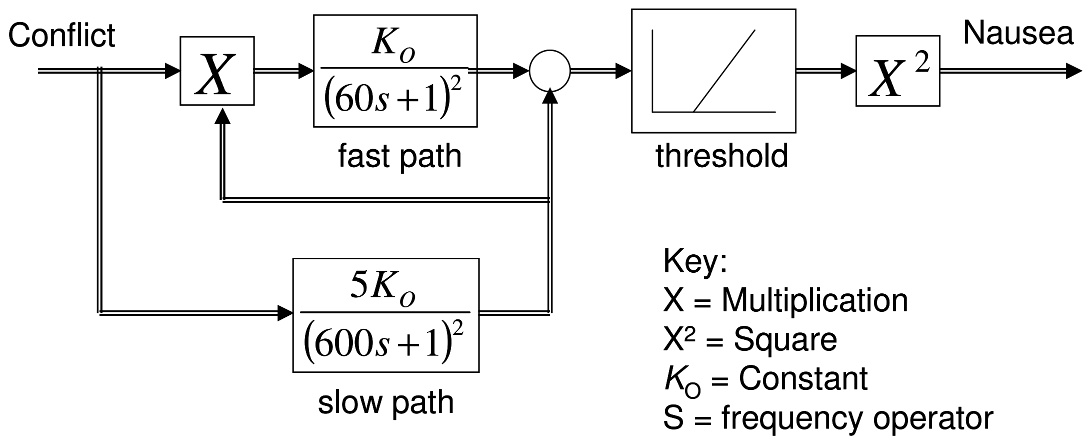


***Figure 3-2: Mathematical model for motion sickness path symptom dynamics,***
*Oman [1990], the fast / slow path elements are second order low-pass filters*

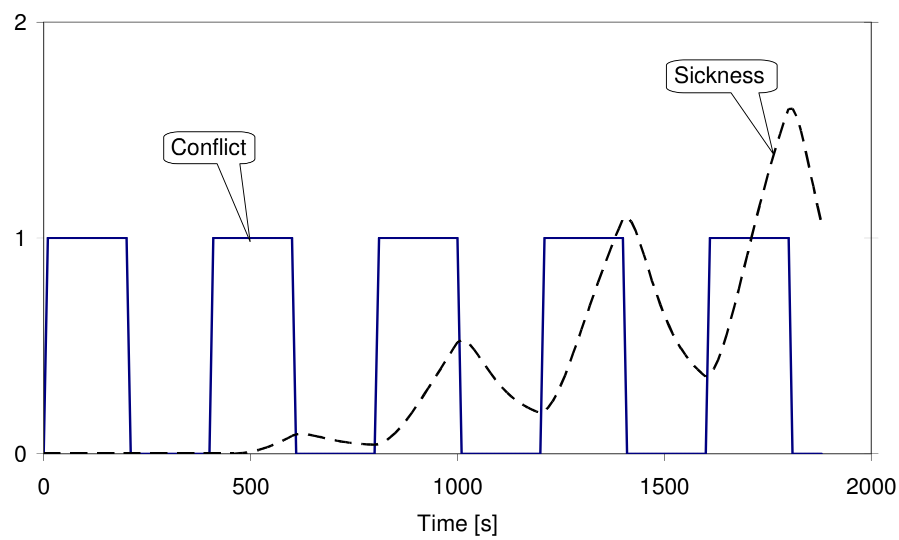


***Figure 3-3: Graphic visualizing of Oman's model***
*conflict input toggles between 0 and 1*

The approach taken by Oman is rather difficult to apply on track testing due to its complexity. ISO [1997] has taken a more practical approach in the *Motion Sickness Dose Value* (MSDV) dependence of time indicating the *vomiting* frequency in percent.

$$MSDV_z(t) = \quad k_{MSDV} \cdot \sqrt{\int_0^{\tau} a_{wf}^2(t) \cdot dt} \qquad [3\text{-}1]$$

where $a_{wf}(t)$ is the frequency-weighted vertical acceleration [m/s²] and $k_{MSDV} = 1/3$ [$s^{1,5}$/m] for a mixed population of male and female adults. Griffin [1990] has based on the $MSDV_z(t)$ derived the illness rating $IR(t)$ as:

$$IR(t) = \frac{MSDV_Z(t)}{50} \qquad [3\text{-}2]$$

where $IR(t)$ is applied on a scale from 0 (feel all right) to 3 (feel dreadful).

Motion sickness dose value can be used with other descriptions of motion than the weighted vertical acceleration, but will always give a value increasing with time.

Kufver and Förstberg [1999] derived the Net-Dose time dependence *ND(t),* which only has one first order path, Figure 3-4.

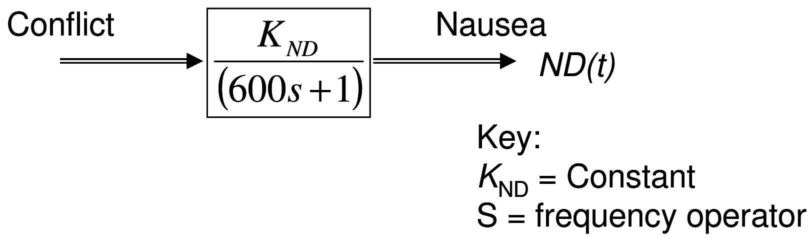


***Figure 3-4: Mathematical model for the Net Dose model***
*The path element is a first order low-pass filter, here with a time constant of 600 seconds*

*ND(t)* can be applied on any description of conflict, but lateral acceleration and roll velocity are most common. The capability to depict increasing and decreasing motion sickness makes it together with its simplicity useful for evaluation of on-track testing.

Förstberg [2000] suggests 12 minutes as time constant, a value taken from the recovery after being motion sick. Förstberg et al [2005] reports time a constant in the same range, but indicates that value vary at lot. The variation could be depending on the sensitivity threshold, Figure 3-2. This threshold corrupts the time constant at fall ill, and was the reason why Förstberg used the recovery only when he calculated the time constant. Förstberg et al [2005] reported time constants taken from variable exposures derived at tilting train tests.

There are also indications that the time constant is depending on the degree of motion sickness, Golding et al [1995] report time constants in the range of 3 to 5 minutes for low degree of motion sickness. Golding and Stott [1997] found a clear difference between subjective reports and objective measurements on motion sickness. The subjective reports gave much shorter time constants at recovery, about 4 minutes, than the objective measurements, which gave about 15 minutes.

## 3.5 *Habituation*

The human has the ability to recalibrate its balance system when information from the different receptors does not correspond. This ability is called habituation or adaptation and has been observed since long time at sea. Habituation is made to one specific environment while other motions may still cause motion sickness. Habituation to space environment may be an exception which seams to give immunity to other motions. The time constant for habituation has been the subject of several researchers. McCauley et al [1976] made a test where they selected persons that gave motion sickness incidence (vomiting) in an initial test. They followed up with the same exposures for five consecutive days. The habituation series resulted in a decrease in motion sickness incidence ending at 30% on day 5. McCauley used vertical acceleration at 0,25 Hz and 0,22 m/s$^2$ r.m.s. in two hours as exposure. Förstberg [2000] come to similar results with subjects exposed to lateral acceleration combined with roll in an experiment simulating tilting train conditions in 30 minutes at four different occasions at four different test days, Figure 3-5.

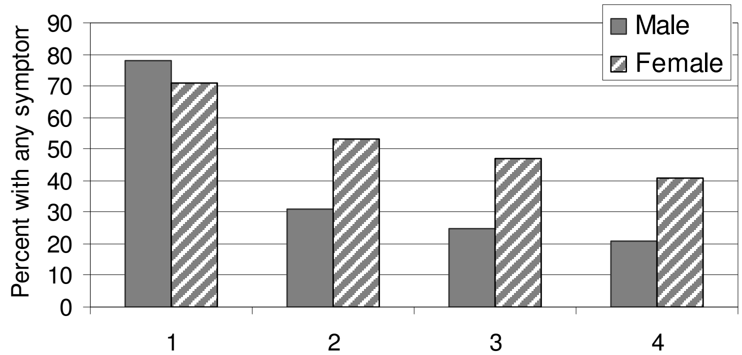


***Figure 3-5: Percent of test subjects with any symptom as function of turn,*** *Förstberg [2000]. The tests were performed in four different days.*

Most researchers have reported time constants for habituation in the range of 3 to 5 days, but the effect can also be observed after a few hours, Kaplan [1964]. Habituation has been observed at motion sickness tests on tilting trains where test subjects recover from motion sickness at maintained stimuli.

Other researchers have taken a more theoretical approach to habituation by seeking the base behind habituation. DiZio and Lackner [1991] have shown good correlation between velocity storage time constant and habituation, habituation lowers the time constant. There is also evidence that the time to get habituated is much less than the time to get weaned, Dai et al [2003]. Figure 3-6 show the relation between velocity storage time constant and habituation as function of test day.

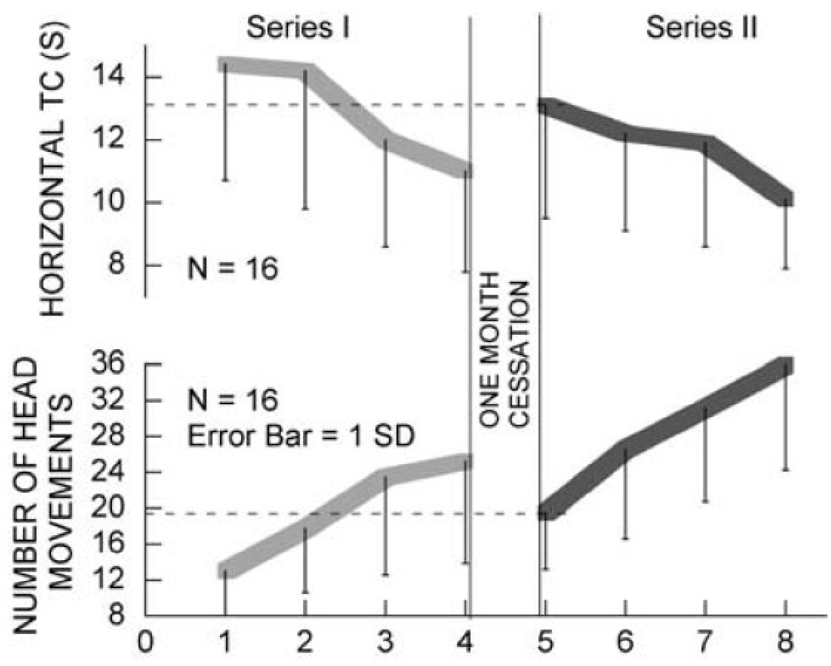


***Figure 3-6: The relation between velocity storage time constant and habituation****, Dai et al [2003], expressed as number of head movements before reaching a certain level of motion sickness. The tests within a series were performed in four consecutive days with one month cessation between the two series.*

# 4 Motions in trains

## 4.1 *Nominal motion quantities*

Motion sickness is correlated to low frequencies. Motion amplitudes of these low frequencies can approximately be calculated from speed and nominal track and train data. The purpose with this calculation is to identify any sensory conflict or misinterpretation of motion.

Assume that a tilting train is running at 180 km/h and passing a curve giving 3 $m/s^2$ in the horizontal plane, 2 $m/s^2$ in track plane and 1 $m/s^2$ in carbody plane. This circular curve is connected to straight track with a clothoid transition curve that takes 3 seconds to pass. Let us also assume that the track and train are without deviations from nominal and that a head follows the carbody. The calculated motion quantities for tilting trains are also compared to those for a non-tilting train running at 147 km/h passing the same circular curve and the same curve transition, Table 4-1 and Table 4-2.

***Table 4-1:*** ***Nominal motion quantities in circular curves,*** *values for non-tilting trains in parenthesis*

| Sensor | Translational acceleration [$m/s^2$] | | | Rotational velocity [deg/s] | | |
|---|---|---|---|---|---|---|
| | Longitudinal | Lateral | Vertical | Roll | Pitch | Yaw |
| Vestibular | 0 | 1 | 0,4 | 0 | 0,7-> 0 | 3 [3)] -> 1 |
| | (0) | (1) | (0,1) | (0) | (0,3-> 0) | (3 [3)] -> 1) |
| Proprioceptive | 0 | 1 | 0,4 | - | - | - |
| | (0) | (1) | (0,1) | | | |
| Visual [1)] | 50 [2)] | 0 [2)] | 0 [2)] | 0 | 0,7 | 3 |
| | (41) | (0) | (0) | (0) | (0,3) | (3) |

1) External view assumed
2) Translational velocity [m/s]
3) The initial value is derived from rotational velocities in the transition curve, which fades out, a lower value derived from lateral acceleration in the circular curve remains

***Table 4-2:*** ***Nominal motion quantities in curve transitions,*** *values for non-tilting trains in parenthesis*

| Sensor | Translational acceleration [$m/s^2$] | | | Rotational velocity [deg/s] | | |
|---|---|---|---|---|---|---|
| | Longitudinal | Lateral | Vertical | Roll | Pitch | Yaw |
| Vestibular | 0 | 0 -> 1 | 0 -> 0,4 | 4 | 0 -> 0,7 | 0 -> 3 |
| | (0) | (0 -> 1) | (0 -> 0,1) | (2) | (0 -> 0,3) | (0 -> 1) |
| Proprioceptive | 0 | 0 -> 1 | 0 -> 0,4 | - | - | - |
| | (0) | (0 -> 1) | (0 -> 0,1) | | | |
| Visual [1)] | 50 [2)] | 0 [2)] | 0,1 [2, 3)] | 4 | 0 -> 0,7 | 0 -> 3 |
| | (41) | (0) | (0,04) | (2) | (0 -> 0,3) | (0 -> 3) |

1) External view assumed
2) Translational velocity [m/s]
3) Window seat assumed

The sensory conflict between vestibular organs and the visual impression is evident in the circular curves after the rotation velocity derived in the transition curve has faded out. There is a conflict also with internal visual reference as the visual reference does not see any motion. There is no sensory conflict in the transition curves, but instead rotations in multiple directions are persistent. Rotation velocity in two directions induces perceived acceleration in the third direction usually called the Coriolis cross-coupling.

There is also a question of interpretation, assuming that the passenger closes the eyes, the passenger will then trust the vestibular organs sensing a low lateral acceleration, which converted to yaw motion give a lower rotational velocity than actual. Misinterpretation becomes a problem when any other motion is added, like head motions.

Comparing calculated motion quantities for tilting trains with non-tilting trains, large relative differences are found in vertical acceleration; pitch velocity and roll velocity (only curve transitions). One or more of these motion quantities can possibly have a relation to motion sickness as tilting trains cause more motion sickness than non-tilting trains.

## 4.2 *Measured motion quantities*

Motions have been measured several times in trains with the purpose of correlating motion to motion sickness. The difference between non-tilting and tilting rolling stock has received particular interest. This was also the base for the FACT project, which performed tests in several countries to receive as wide spread of cases as possible. Some of the tests were performed in Norway on the track section between Kristiansand and Vegårdshei which contains numerous curves with approximately 300 meter radii. Table 4-3 gives data for selected test cases.

***Table 4-3: Data for selected tests between Kristiansand and Vegårdshei***

| | Non-tilting case | Tilting case |
|---|---|---|
| Maximum lateral acceleration in track plane [m/s$^2$] | 1,0 | 1,8 |
| Maximum lateral acceleration perceived by passengers [m/s$^2$] | 1,0 | 0,8 |

A tilting train of type BM73 was used for all tests, the non-tilting case was received as zero compensation of lateral acceleration and the tilt was just compensating the suspension sway. The interesting quantities were measured and are here given as examples of motion levels in trains, Table 2-9 (r.m.s.-values), Figure 4-1 to Figure 4-6 (PSD-diagrams).

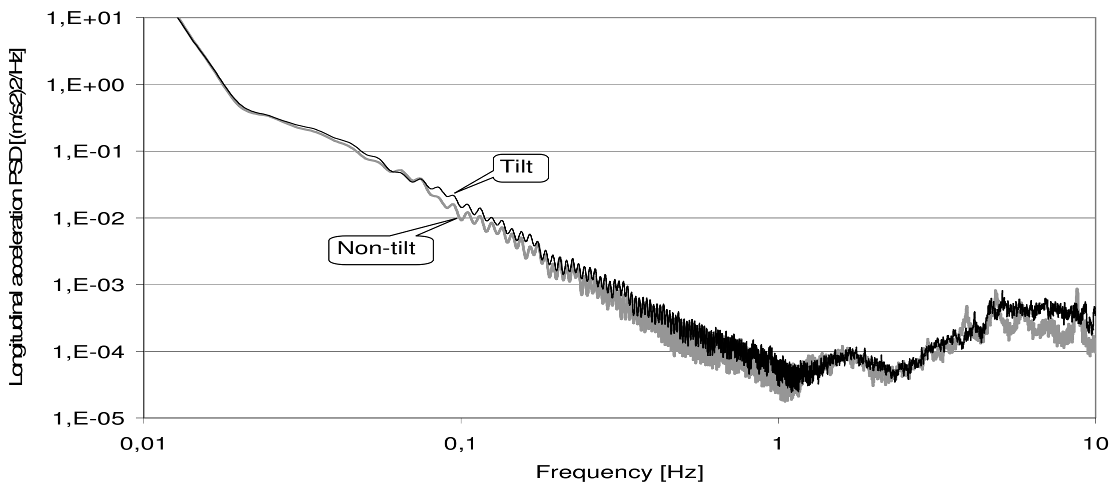


*Figure 4-1: Carbody longitudinal acceleration in tilting and non-tilting trains*

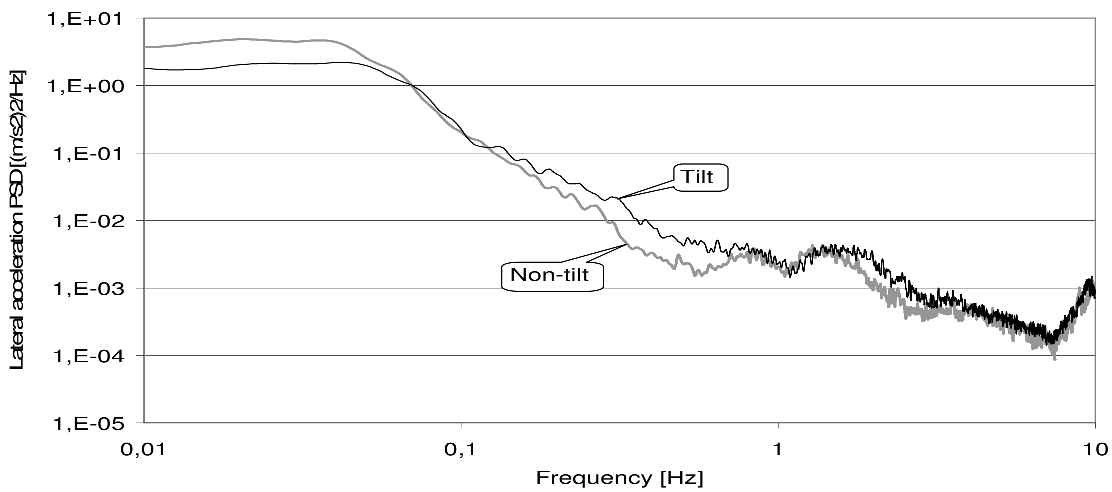


*Figure 4-2: Carbody lateral acceleration in tilting and non-tilting trains*

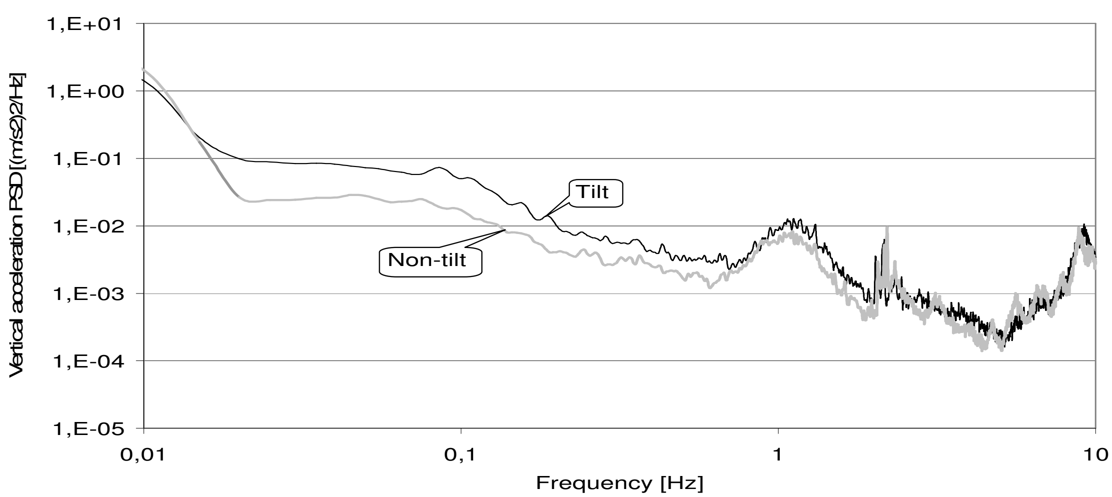


*Figure 4-3: Carbody vertical acceleration in tilting and non-tilting trains*

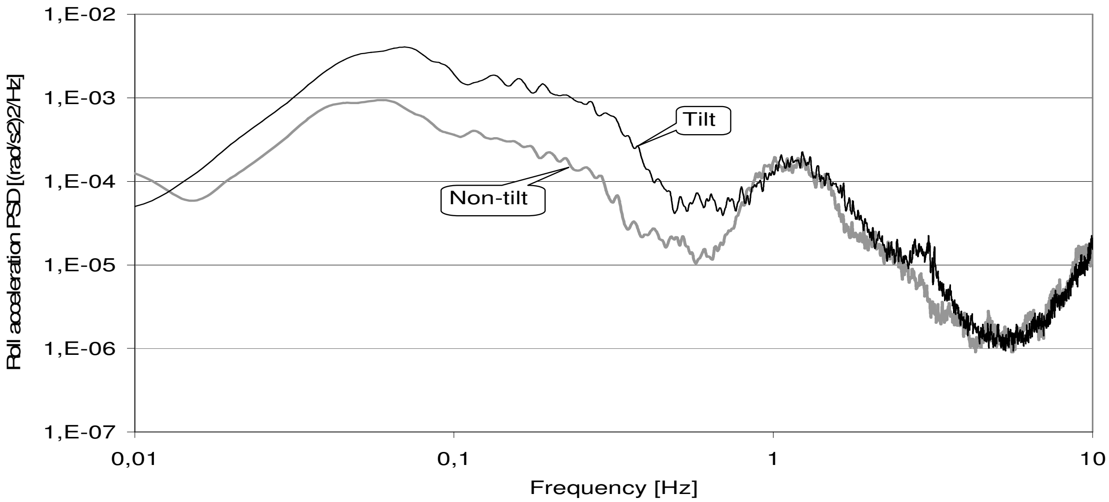


*Figure 4-4: Carbody roll acceleration in tilting and non-tilting trains*

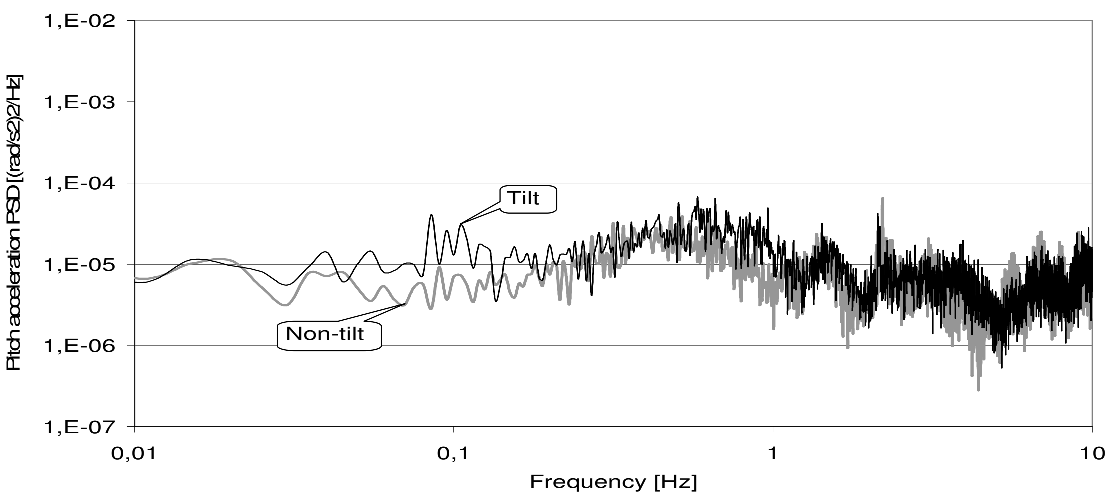


*Figure 4-5: Carbody pitch acceleration in tilting and non-tilting trains*

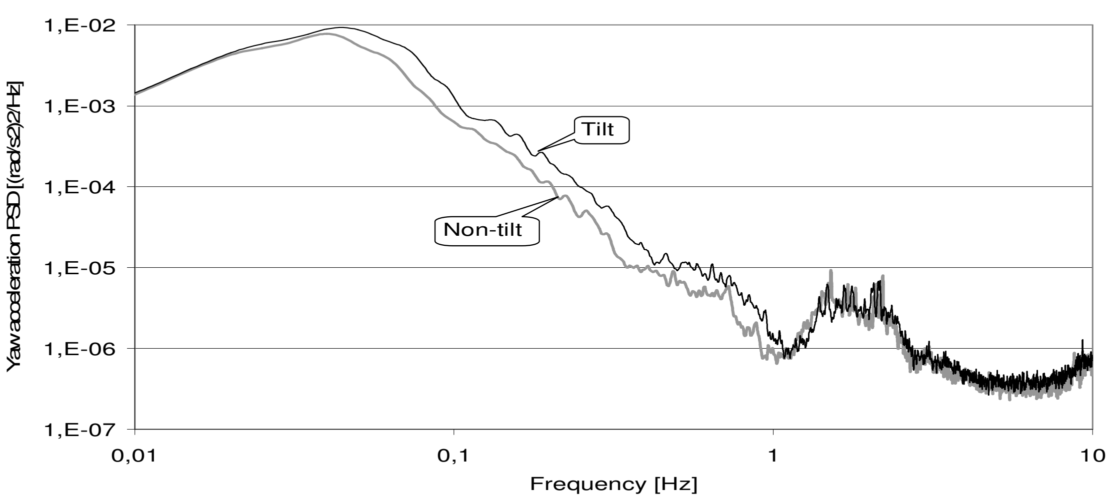


*Figure 4-6: Carbody yaw acceleration in tilting and non-tilting trains*

Comparing measured motion quantities given in this section with the nominal motion quantities calculated in Section 4.1 a few differences are noticeable:

1) The measured lateral acceleration is significantly lower at low frequencies for the tilting train than for the conventional, where the calculation gave no difference.

2) The measured difference in vertical acceleration is significantly lower than indicated in the calculation based on nominal track and train data.

The likely reason for these differences is speed restrictions to a lower speed than given by the maximum allowed cant deficiency, i.e. there are other speed limiting factors like platforms, signalling and bridges. The vertical acceleration is also influenced by the vertical track alignment.

Knowing that tilting trains cause more motion sickness than non-tilting trains it seams obvious, looking at Figure 4-1 to Figure 4-6 that vertical acceleration and/or roll acceleration are the cause of motion sickness in tilting trains. However correlation between motion variables exists, which excludes the possibility to, based on measurements in trains, judge which motion quantity is the main cause of motion sickness. Knowing the main cause is the key to reduce motion sickness as there are different means to reduce different motion quantities. Table 4-4 shows the correlation at one test, but with different compensation ratios in the different cars. Considering more than one test improves the situation but correlation maintains a problem.

***Table 4-4:*** ***Correlation between different motion quantities at a tilting train test with different compensation ratios,*** *Norwegian BM73 running Kristiansand – Vegårdshei – Kristiansand at tilting speed.*

| | *Longitudinal* | *Lateral* | *Vertical* | *Roll* | *Pitch* | *Yaw* |
|---|---|---|---|---|---|---|
| Longitudinal | 1 | | | | | |
| Lateral | 0,85 | 1 | | | | |
| Vertical | 0,86 | 0,94 | 1 | | | |
| Roll | 0,84 | 0,93 | 0,99 | 1 | | |
| Pitch | 0,81 | 0,85 | 0,96 | 0,98 | 1 | |
| Yaw | 0,89 | 0,92 | 0,98 | 0,98 | 0,95 | 1 |

Note: All translations are given as accelerations, all rotations as velocities

## 4.3 *Motion quantities – experienced motion sickness*

One interesting question to study is if motion quantities specifically measured in tilting trains have caused motion sickness in laboratories. The comparison here is made to laboratory tests where the test subjects were seated in a similar way as in trains. The motion quantities in tilting trains are taken from tests performed in Norway on the track section between Kristiansand and Vegårdshei which contains numerous of curves with approximately 300 meter radii.

The result of this comparison is shown in Table 4-4. All the laboratory tests causing motion sickness have been performed at amplitudes higher than measured in tilting trains. In particular this is the case for rotations. The lateral accelerations used in laboratory by Donohew & Griffin [2004b] and vertical accelerations used in laboratory by O'Hanlon & McCauley [1973] were only 60 – 70% higher than measured in tilting trains on the track section between Kristiansand and Vegårdshei. However, the lateral acceleration in the non-tilting train, which causes less motion sickness, is even higher than in the tilting train.

*Table 4-5: Comparison between laboratory and tilting train tests*

| | Laboratory | | | | Tilting train |
|---|---|---|---|---|---|
| | Ref [1)] | Frequency [Hz] | R.m.s amplitude [$m/s^2$, deg/s] | Sickness | R.m.s. amplitude [$m/s^2$, deg/s] |
| Lateral acceleration | D | 0,125 | 0,56 | 30% nausea (½h exposure) | 0,35 [2)] |
| | F | 0,167 | 0,78 | 37% nausea (½h exposure) | |
| Vertical acceleration | M | 0,10 | 0,12 | 25% vomiting (2h exposure) | 0,07 [3)] |
| | W [4)] | 0,10 | 0,12 | No sickness (2h exposure) | |
| Roll velocity | W | 0,07 | 10 | 26% nausea (2h exposure) | 1,0 [3)] |
| | F | 0,167 | 4 | 17% nausea [5)] (½h exposure) | |
| Yaw velocity | G | 0,02 | 110 | 8% vomiting (5m exposure) | 0,7 [3)] |

1) D) Donohew & Griffin [2004b]
M) O'Hanlon & McCauley [1973]
W) Wertheim et al [1995]
F) Förstberg [2000]
G) Guedry et al [1982]

2) Weighting curve Wg applied [Donohew & Griffin, 2004b]

3) Weighting curve Wf applied [ISO, 1997]

4) Wertheim et al repeated O'Hanlon & McCauley test, but without head support

5) Laboratory tests always cause some nausea independently of motion, Förstberg did not consider this case to cause motion sickness

# 5 Discussion and conclusion

## 5.1 *Discussion*

The number of researchers and the number of reports written on the subject of motion sickness is huge. Some of the theories are contradictory to each other; like for hypothesis of motion sickness. Models derived from on-track tests with trains differs, and contradict the theories. At least part of the problem seams to be due to individual differences between test subjects. Sometimes these differences can be set in suitable groups, like young people are more sensitive than adults and females are more sensitive than males. Some researchers try to solve this problem by using only one particular group of test subjects, but there are still differences within groups. The methods in performing tests are also very different; it is therefore important that results are viewed together with the test conditions.

Attempts to find the cause of motion sickness by relating to motions measured in a vehicle have generally failed due to strong correlation between variables. Correlation between motion sickness to one or more variables is usually found at these attempts, but still the related variable can not be pointed out as the prime cause of motion sickness.

All the laboratory tests causing motion sickness have been performed at amplitudes higher than measured in tilting trains. In particular this is the case for rotations. The lateral accelerations used in laboratory by Donohew & Griffin [2004b] and vertical accelerations used in laboratory by O'Hanlon & McCauley [1973] were only 60 – 70% higher than measured in tilting trains on the track section between Kristiansand and Vegårdshei. It should be noted that different weighting curves are applied in vertical and lateral directions, using the lateral weighting curve in vertical direction eliminates the magnitude difference between laboratory tests and tilting trains.

Possibly vertical acceleration alone can be the cause of motion sickness in tilting trains, but it is more likely that a combination is more provocative (Section 5.3). Movement of the head has since early 1800s been pointed out as one good combination candidate. Note that vertical acceleration in tilting trains is a measure on the angle between the real vertical axis and the believed vertical axis. This angle difference is according Bles et al [1998] the cause of all motion sickness when combined with self controlled motions (in particular head motions) resulting in conflict between expected and experienced motion feedback.

## 5.2 *Conclusion*

Evidence of motion sickness has been reported in air, in space, at sea, in cars, in trains, at skating, at fairground rides etc. and there are plenty of examples for each. Motion sickness is most common in cars and on cruise ships. Dominant frequencies for vehicles experiencing motions sickness are often at 0,2 Hz or below.

Laboratory tests have proven that translations in all directions can cause motion sickness; it is only a question of magnitude. Weighting curves exists as results from the laboratory tests, with sensitivity peaks at frequencies of 0,2 Hz or below. Pure rotations seam to have less correlation to motion sickness than translations. Combinations of motions, in particular translation combined with rotation, are highly effective in creating motion sickness.

The sensory conflict is the most common explanation of motion sickness. Most researchers have today accepted the sensory conflict theory, but there are also competing theories; like the over-stimulation theory and the ecological theory. The time dependence of motion sickness has confused researchers by showing contradictory results depending on evaluation method. The threshold at fall ill disturbs the calculation of time dependence if not considered.

Motion quantities measured in tilting trains differ from motion quantities measured in non-tilting trains by increased levels of vertical and roll motions at frequencies below 1 Hz. These increased levels of motions may contribute to the difference in experienced motion sickness between non-tilting and tilting trains. Correlation between vertical, roll and other motions exists, which excludes the possibility to, based on measurements in trains, judge which motion quantity is the main cause of motion sickness.

## 5.3 *Suggestions for further research*

Further research should be made where research can improve the competitiveness of tilting trains. Vertical acceleration is found to have a relation to motion sickness in the model proposed by Förstberg et al [2005], but it can not describe the differences between different test conditions (different lines, different tilt compensation ratio etc.) in a proper way. The correlation between a certain motion and its impact on the onset of motion sickness is important for reducing motion sickness. In particular we are interested in the limited set of variables which can be influenced and controlled in the tilting train itself or by modifications of the track geometry. The tilt angle as function of cant deficiency is one variable in the train that can be changed and the cant and length of transition curves are two variables in the infrastructure that can be changed. However, knowledge of their impact on motion sickness is needed to make the optimum choice.

Further evaluation of already performed motion sickness test is one possible and cost effective way to improve knowledge by:

- Including combined motions in motion sickness model
- Including threshold in motion sickness model
- Alternative frequency weighting of motions
- Evaluation of test subjects (gender, age, habituation, illness at start etc.)

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# Annex A. FACT Motion sickness questionnaire

*How would you describe the driving comfort the last 5/10 minutes?*

Very bad Very good

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

*How would you describe your feelings of nausea right now?*

None Very strong

| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 |

And additionally the following question was asked on the Swedish and Norwegian runs respectively:

Swedish questions

*How would you characterize your nausea, just now?*

You may tick more than one box.

☐ Headache
☐ Tiredness
☐ Feeling hot
☐ Cold sweating
☐ Drowsiness
☐ Dizziness
☐ Nausea
☐ No motion sickness symptoms

Norwegian questions

*How would you characterize your feeling of motion sickness, just now?*

You may tick more than one box.

☐ No symptoms at all, I feel fine
☐ Some mild symptoms, but not nausea nor dizziness
☐ Mild dizziness
☐ Mild nausea
☐ Moderate nausea
☐ Dizziness
☐ Strong nausea
☐ I do not feel well