Analysis and Modeling of Motion Sickness related studies in Vehicles

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What is Motion Sickness?

Motion sickness is nausea caused by motion, especially when traveling in a vehicle . Other symptoms include vomiting, headaches, sweating, increased salivation, drowsiness, dizziness, and warmth/flushing. Individuals with motion sickness also exhibit pallor (loss of skin color). Sometimes this term is more specifically identified (Car Sickness, seasickness, airsickness, space sickness, simulator sickness, or virtual reality sickness).

What causes Motion Sickness?

Motion sickness occurs when spatial orientation – in which direction the body is pointed, in which direction it is moving, and about which axes it is rotating – is disrupted. Motion is sensed by the brain through 3 different pathways of the nervous system, (1) the inner ear (sensing motion, acceleration, and gravity), (2) the eyes (vision), and (3) the deeper tissues of the body surface (proprioceptors). Feedback from the muscle and joint sensory receptors can also be important.Motion sickness is more likely when movements are slow and involve multiple simultaneous movements along or about movement axes Stott (1986) identified 3 core rules, which if violated, could result in motion sickness.

Rule 1. Visual–vestibular: motion of the head in one direction must result in motion of the external visual scene in the opposite direction;

Rule 2. Canal–otolith: rotation of the head, other than in the horizontal plane, must be accompanied by appropriate angular change in the direction of the gravity vector;

Rule 3. Utricle–saccule: any sustained linear acceleration is due to gravity, has an intensity of 1 g and defines “downwards.”

Prediction of MSI

Probably the best known quantitative model is that in ISO 2641. That model predicts the Motion Sickness Index, here for vertical accelerations using a spectral weighting function as described below. In addition, there are also predictions for the motion sickness dose value for short exposures.

$$MSI = 100[0.5 \pm \mathrm{erf}\left(\frac{\pm \log_{10}\frac{a_v}{g} \pm \mu_{MSI}}{0.4}\right) \quad (1)$$

where:
MSI – motion sickness incidence index;
erf – error function;
av – mean value of vertical accelerations at a selected point;
μMSI – parameter calculated from this equation:

$$\mu MSI = -0.819 + 2.32(\log_{10}\omega_e)^2 \quad (2)$$

The weighting function We has a peak at 0.167 Hz.
In addition, ISO 2631 specifies the computation of the motion sickness dose value (MSDV), the percentage of people who have motion sickness symptoms, in particular the percentage of subjects who will vomit when exposed to 2 hours of constant sinusoidal vertical acceleration. If measurements are performed over a short exposure period, MSDV is expressed as follows:

$$MSDV = \bar{a}_v T_0^{1/2}$$

where:
$\bar{a}v$ – mean value of vertical acceleration;
T0 – time of exposure recording;
If measurements are performed over a long period of exposure, MSDV is expressed as follows:

$$MSDV = \sqrt{\int_0^T (a_v(t))^2 dt}$$

where:
av – vertical acceleration referred to a given frequency, accounting for the weight [3]
T – exposure period.

Drivers receive both acceleration and rotational stimulation when negotiating a curve, and it is known that they will tilt their head toward the center of the curve. It has also been found that the head movement of passengers is opposite to that of the driver, that is, they tilt their heads in the direction of the centrifugal force. Because passengers tend to be more susceptible to car sickness than are drivers, we assumed that the driver's head movement is related to a decreased likelihood of carsickness and a corresponding increase in comfort. Thus, it is expected that an analysis of drivers' active head-tilt motions can lead to the design of a vehicle with a more comfortable motion

The Vestibular System

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

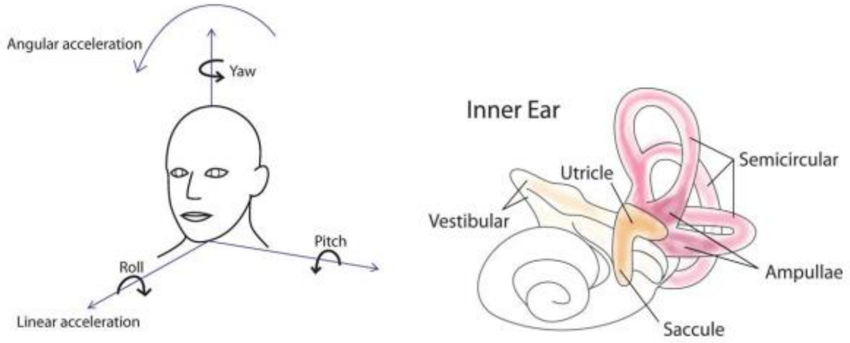


Fig. 7. Description of roll, pitch and yaw rotation, angular and linear acceleration and to the right a description of the inner ear. Inspiration for drawings were found at Evolve media.

Patent 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).

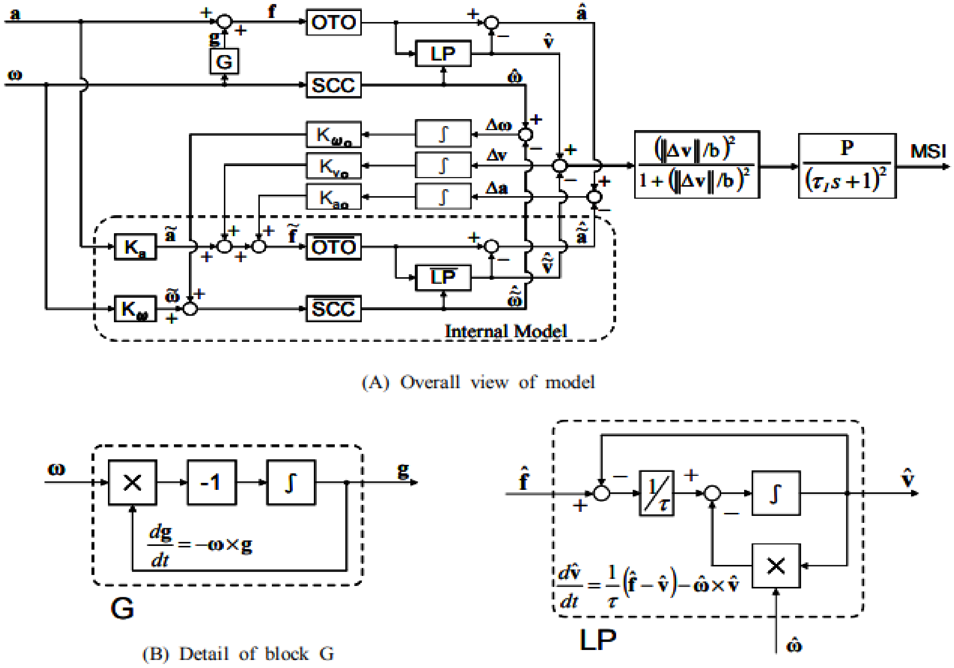
6. Another patent that intend to reduce motion sickness is a driving support device that detects the position of an occupants head and notifies the driver that there is a possibility of car sickness (TAKERO, 2005).

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).

Modelling of Motion Sickness Mechanism

Referring to *Modeling and Validation of Carsickness Mechanism by Norimasa Kamiji ,Yoshinori Kurata , Takahiro Wada and Shun'ichi Doi*



(A) Overall view of model

(B) Detail of block G

(C) Detail of block LP

Fig.1 3D-SVC(three-dimensional subjective vertical conflict) model[10].

According to the Einstein's equivalence principle, the resultant force f of gravity g and inertia force a will work on otolith at the same time.

$$\mathbf{f} = \mathbf{a} + \mathbf{g}\,. \qquad (1)$$

It was general to assume the existence of the low-pass filter as an answer to this question so far. In recent years, however, it is thought that the angular velocity information ω from semicircular canal plays a major role, and that the recognition of subjective vertical follows the next time-varying linear system.

$$\frac{d\mathbf{v}}{dt} = \frac{1}{\tau}(\mathbf{f} - \mathbf{v}) - \boldsymbol{\omega} \times \mathbf{v}\,, \qquad (2)$$

where τ is time constant. It is generally understood that the sensory conflict theory as the cause of “Motion sickness” and some models were proposed.

Considering that the vertical conflict occurs by rotation stimulus and developed a three dimensional nervous system model by applying the Eq. (2) to the Bos’s Model (Fig.1 (A)). In Fig.1 (A), block G is equation that shows rotation of rigid body, and it is direction of gravity seen from head reference frame, when it assumes that gravity is constant. Fig.1 (B) shows detail of block G. OTO is the otolith organ and is assumed as unit matrix from its dynamic response characteristics. SCC is semicircular canals and it is described as follows.

$$\hat{\omega}_i = \frac{\tau_d \tau_a s^2}{(\tau_d s + 1)(\tau_a s + 1)} \omega_i \quad (i = x, y, z),$$

OTO bar is internal model of OTO and it is unit matrix. SCC bar is internal model of SCC and it is described as follows.

$$\hat{\tilde{\omega}}_i = \frac{\tau_d s}{\tau_d s + 1} \tilde{\omega}_i \quad (i = x, y, z). \qquad (4)$$

By using 3D-SVC model, we simulated MSI at simple rotation and translation oscillation. Table 1 shows model parameters. Figure shows simulation result of vertical and horizontal oscillation. A frequency vs. root mean square acceleration distribution of MSI like saddle-shaped distribution characteristic is similar other experimental data and simulation result. In addition, Figure shows distribution characteristic of MSI by roll and pitch motion.

Tab.1 Three Dimensional SVC Model parameters[10]

K_a	K_ω	K_{ω_c}	K_{v_c}	K_{a_c}
0.1	0.8	5.0	5.0	1.0
τ_d [s]	τ_a [s]	b [m/s²]	τ_I [min]	P [%]
7.0	190.0	0.5	12.0	85.0

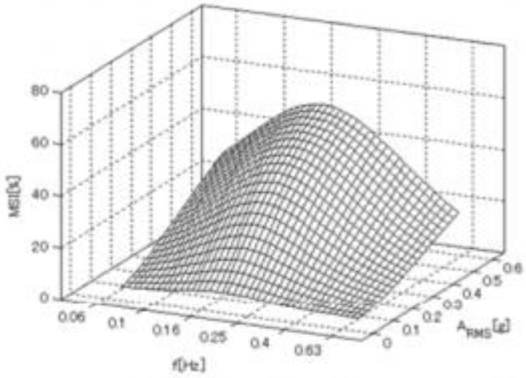


Fig.2 Predicted MSI from horizontal and vertical[10] oscillation

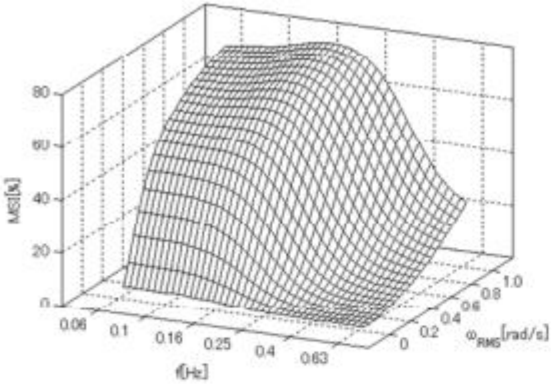


Fig.3 Predicted MSI from roll and pitch oscillation[10]