Influence of Different Alternatives of Tilt Compensation on Motion-Related Discomfort in Tilting Trains

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INFLUENCE OF DIFFERENT ALTERNATIVES OF TILT COMPENSATION ON MOTION-RELATED DISCOMFORT IN TILTING TRAINS

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Abstract

Train speed may be increased by constructing new railways with improved curve geometry or by using tilting trains. The tilting system compensates the lateral acceleration in curves by tilting the car body, thus allowing trains to run 25-35 % faster on existing curved tracks. Although motion sickness in tilting trains seems to be a small problem for most passengers it can be a problem to those prone to nausea. To investigate the frequency of motion sickness and how different tilt compensation strategies influence the occurrence of such symptoms, a full-scale test ride was conducted on a curved track. 200 healthy volunteers were employed, selected for high subjective sensitivity to nausea, in three different experiments. Altogether six alternatives were tested. Four times per test ride the subjects answered a questionnaire concerning vegetative symptoms, fatigue, sleepiness and nausea.

The test persons' overall estimation of average ride comfort was good in all alternatives, however, some persons reported symptoms of motion sickness. A 55% degree of tilt compensation instead of the normal 70%, reduced the number of test persons reporting dizziness and nausea by about 30 - 50%. There are also indications that limited tilt speed and/or tilt acceleration can reduce symptoms. The ride comfort was also estimated as slightly better in these alternatives.

Key words: Motion sickness, high speed trains, comfort.

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Introduction

Railway companies throughout the world look for ways to increase train speeds as well as ride comfort. As most countries have a significant number of curved tracks, measures must be taken to compensate for the lateral accelerations during curving if speed is to be increased and comfort not decline. The constructing of new railways with straighter tracks has been employed in some countries, but many railway transportation companies have found this to be a too expensive method. Another alternative is then to make the car bodies of the train tilt inwards during curving. It is believed to be favourable to compensate for only part of centrifugal forces in the curves. This way the trains may go 25-35% faster on existing tracks. In Sweden, the preferred compensation strategy method for the X2000 train has been to compensate for 70% of the lateral acceleration forces in the curves, thus allowing a speed increase from a previous maximum of 160 km/h to about 200 km/h. This has reduced the travelling time from e.g. Stockholm to Gothenburg from about 4 hours to about 3 hours.

Although motion sickness in tilting trains seems to be a small problem for most passengers, it can be a problem to those prone to nausea. To investigate the frequency of motion sickness and how different compensation strategies influence the occurrence of such symptoms, a full scale test was launched. Six compensation methods were tested in the three parts of the experiment (Förstberg 1996).

State of the art: Transporting persons has always been associated with occurrence of motion sickness in susceptible individuals. When this applies to the pilot in a military jet aircraft the implications are of course severe (AGARD 1991), but passenger discomfort in aeroplanes is by no means a negligible problem (Benson 1988). No less problems arise in space technology (Crampton 1990). The most widely studied area of motion sickness is the naval area, and the importance of vertical low frequency oscillations was identified (Lawther 1988, Lawther and Griffin 1987, 1988a, 1988b, 1989, Magnusson and Örnhagen 1994). Estimating the impact of different motion patterns on the occurrence of motion sickness has been the subject of many issues of standardization works (BSI 1987, Griffin 1989, 1990, ISO 1985a, 1985b, 1995, Oborne 1976).

Regarding railways, passenger comfort and motion sickness have attracted many works of analysis (Sperling 1941, Sperling and Betzhold 1956, Andersson and Nilstam 1984,

Material and methods

Material: Healthy volunteers were used, selected for high subjective sensitivity to nausea. In the first experiment (Nov. 1994) about 60 subjects took part in a three-hour experiment during one day. The following two days, approximately 80 subjects took part in two sessions of three hours, each on separate days. The third experiment was conducted six months later (June 1995) using roughly 70 subjects and evaluated three different compensation strategies during three consecutive days, with a three-hour train ride every day.

The participants in the first experiment were mostly employees of the railroad company and the manufacturer of the trains. The participants in the last two experiments were mostly students aged of 20 to 30. The test train was X2000 with two intermediate cars (experiment 1 -2) and with four intermediate cars (experiment 3).

Track characteristics: The tests were conducted on a fairly curved track between Stockholm and Linköping. The test track is about 180 km long with permitted speeds from 180 - 200 km/h for 85% of the track length.

Tested compensation strategies: The evaluated parameters of the train ride were compensation of car body lateral acceleration, maximum tilt speed and acceleration, and in one case train speed. Altogether six alternatives were tested, as given in Table 1.
**TABLE 1** Values used in tilting system during the experiments. In the first and second experiments alternatives A-D were used, in the third experiment alternatives A, F and G were used.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Speed</th>
<th>Tilt comp</th>
<th>Car body tilt speed limit</th>
<th>Car body tilt acceleration limit</th>
<th>Result lateral acceleration$^i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>+30</td>
<td>70</td>
<td>4</td>
<td>no limit$^{ii}$</td>
<td>0.6</td>
</tr>
<tr>
<td>B</td>
<td>+30</td>
<td>40</td>
<td>4</td>
<td>no limit</td>
<td>1.0</td>
</tr>
<tr>
<td>C</td>
<td>+10</td>
<td>0</td>
<td>no tilt</td>
<td>no tilt</td>
<td>1.15</td>
</tr>
<tr>
<td>D</td>
<td>+30</td>
<td>70</td>
<td>2</td>
<td>no limit$^{ii}$</td>
<td>0.7</td>
</tr>
<tr>
<td>F</td>
<td>+30</td>
<td>55</td>
<td>4</td>
<td>4</td>
<td>0.8</td>
</tr>
<tr>
<td>G</td>
<td>+30</td>
<td>55</td>
<td>2.3</td>
<td>no limit$^{ii}$</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Remarks: A alternative E was planned but never realised with limited car body tilt acceleration and 70% compensation.

$^i$ Typical maximum values.

$^{ii}$ The car body tilt acceleration was not limited by the program of the tilting system. Due to inertia of car body and stiffness of suspensions and dampers the car body angular acceleration can be estimated to about 10 [°/s^2].

The test pattern during the third experiment (June 1995) was a Latin square design. This design was selected to minimise differences in age, gender and sensitivity in the different test groups, see Table 2.

**TABLE 2** Test pattern sequence for the third experiment (June 1995). Each group was tested in three days with different alternatives to minimise bias because of differences in sensitivity etc.

<table>
<thead>
<tr>
<th>Car # 1</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car # 2</td>
<td>G</td>
<td>A</td>
<td>F</td>
</tr>
<tr>
<td>Car # 4$^i$</td>
<td>F</td>
<td>G</td>
<td>A</td>
</tr>
</tbody>
</table>

Remark: $^i$ Car # 3 was the buffet car and not used as a test car
Evaluation: Each test ride lasted about 3 hours. After each quarter of the test ride (interval approximately 45 minutes) the subjects answered a questionnaire concerning vegetative symptoms, fatigue, sleepiness, dizziness and nausea. The physical parameters of the train ride were recorded for future analysis of possible relations between train movements and motion sickness complaints.

Statistical evaluation: The frequency of complaints in the above parameters was compared between tested compensation strategies using the Chi-square test (Siegel and Castellan 1988).

Results

Women reported two to three times more symptoms than men, therefore the third test used identical proportions of women and men in all test alternatives and groups. The subjective self estimation of sensitivity to motion sickness was also rated higher among women than men.

Motion sickness symptoms

The symptoms of motion sickness incidence (SMSI) as reported in the questionnaires is given in Table 3. Definitions of SMSI were reported dizziness, nausea or not feeling well if the subject felt well before the start of each test run.

TABLE 3 Percentage of subjects with symptoms of motion sickness incidence (SMSI) during the tests, given as incidence per test period (quarter of the 3 h test session). Experiment 3.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>SMSI [%]</th>
<th>Confidence interval</th>
<th>Relative to A [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>11 - 19</td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>5*</td>
<td>0 - 10</td>
<td>33</td>
</tr>
<tr>
<td>F</td>
<td>10*</td>
<td>6 - 14</td>
<td>68</td>
</tr>
<tr>
<td>G</td>
<td>8*</td>
<td>5 - 11</td>
<td>53</td>
</tr>
</tbody>
</table>

Remark: * Alternatives C, F and G deviate significantly from alternative A (p < 0.05)

i 95 % approx confidence interval

In the first and second experiment only alternative C displayed significantly less symptoms than the other alternatives, but the alternatives B and D displayed a potential of a reduction of 25 - 30 % of SMSI compared with alternative A.
In the third experiment both alternatives with 55% compensation (alternatives F and G) were rated significantly better than alternative A, with alternative G displaying a numerically slightly better value of the two. The reduction of SMSI was 30 - 45 % compared with alternative A.

Differences between alternatives A, F and G for different symptoms of motion sickness are shown in Figure 1. Differences among gender are shown in Figure 2. The difference between women and men is about three times for nausea, I don't feel well and SMSI (for experiment 3).

**FIGURE 1** Differences in symptoms of motion sickness for the alternatives A, F and G in Experiment 3
Symptoms of motion sickness
Experiment 3

Time dependence

Analysing the time pattern of the complaints, the incidence of discomfort was highest at the first and the last inquiry during the three-hour ride, see Figure 3.
FIGURE 3 Motion sickness symptoms incidence (SMSI) as function of travel time.

Ride comfort and rated working/reading ability

The tested persons reported both that the ride comfort was slightly improved and with less comfort disturbances in alternatives F and G compared to alternative A. They also rated their ability to read and work slightly higher for these alternatives, see Table 4.

TABLE 4 Comparison of estimated ride comfort, percentage of subjects complaining of comfort disturbances due to low-frequency lateral accelerations and estimated working / reading ability

<table>
<thead>
<tr>
<th></th>
<th>Estimated ride comfort</th>
<th>Comfort disturbances lateral accelerations</th>
<th>Estimated work / read ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative A</td>
<td>4.1</td>
<td>58</td>
<td>4.06</td>
</tr>
<tr>
<td>Alternative F</td>
<td>4.2</td>
<td>54</td>
<td>4.13</td>
</tr>
<tr>
<td>Alternative G</td>
<td>4.2</td>
<td>54</td>
<td>4.20</td>
</tr>
</tbody>
</table>

Remark: i On a five-grade scale from very bad (1) to very good (5)
Discussion

The mechanisms of motion sickness are not entirely known. The most popular is the sensory conflict theory (Reason 1974, Reason and Brand 1975, Reason 1978, Stott 1986, Benson 1988, Oman 1990), while others have advocated that the motion sickness response is a protection function for the body integrity (Treisman 1977, Money 1991). It seems clear that the vestibular organs are a necessary part of the reaction (Henriksson et al. 1972).

This study evaluated the motion discomfort experienced by healthy subjects in a high-speed train, utilising active tilting of the car body during curving to reduce the lateral acceleration. By using a lower degree of compensation instead of the normal 70%, a reduction of up to 30 - 50 % of the number of test persons reporting dizziness and nausea was found. The alternatives employing a compensation of 55% were found to be the most favourable ones. Women reported about three times as many symptoms as men. There are indications that limited tilt speed or tilt acceleration can also reduce symptoms. As complaints were most frequent at the first and the last inquiry of the three-hour ride, it is suggested that not only the cumulative motion dose\(^1\) is responsible for the symptoms of motion sickness to occur.

These results are not directly transferable to a normal population of travellers, because they were selected both for high sensitivity ages and the subjects were mostly between 20 - 30 years old. But it is believed that a reduction of symptoms in a group of high sensitivity also reduces the symptoms in a more normal group.

In the second half of the project, an analysis of the relations between measurable physical ride parameters and incidence of motion sickness symptoms is planned to be conducted.

It is important to have matched test groups especially considering gender and sensitivity to motion sickness. All test groups should test all alternatives to minimise errors.

\(^{1}\) Motion Sickness Dose Value. MSDV\(_{Z}\)

\[
MSDV_{Z} = \left[ \int_{0}^{T} a_{w}^{2}(t)dt \right]^{1/6} \quad [m/s^{1.5}] \text{ there } a_{w}(t) \text{ is frequency-weighted acceleration.}
\]

Percentage of persons who may vomit = \(K_{m} \cdot MSDV_{Z} \) [%] and \(K_{m} = 1/3\) for a mixed of unadapted male and female adults (ISO 1995).
Future research has to understand the influence of lateral and vertical acceleration, also roll angle speed and roll angle acceleration on motion sickness. This should be a way to minimise complaints of discomfort and therefore enhance ride comfort and ability of working on future high-speed tilting trains.

**Acknowledgements**

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