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# Quantitative analysis of time-course development of motion sickness caused by in-vehicle video watching

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ABSTRACT

It has been common and popular to watch videos in moving vehicles. An important issue in developing comfortable in-vehicle video watching systems is to understand how passengers get motion sickness. With this in mind, the goals of this paper are (1) to introduce an experimental protocol and a statistical analysis procedure for quantitatively evaluating how motion-sickness is developed during car-driving, and (2) to demonstrate their practical usefulness with a working experimental study. In the experimental protocol, motion sickness was induced to subjects by requiring them to watch an in-vehicle video during 15-min driving, and the time-course development of motion sickness was recorded by asking subjects to evaluate their degree of motion sickness every one minute. A main difficulty in analyzing data from these studies is how to incorporate the individual difference in motion-sickness susceptibility. Since susceptibilities are markedly different among subjects, within-subject design experiments are preferred. However, it is practically difficult to conduct complete set of trials because subjects who are not willing to continue experiment (due to heavy motion sickness) should be able to withdraw from the subsequent series of trials in accordance with ethical requirement. To cope with this incomplete data issue, we introduce a statistical data analysis procedure that enables to estimate and impute missing entries in the within-subject design table. Using a working example, we demonstrated that the protocol and the procedure are useful for quantitative assessment of the time-course motion sickness development. We conducted an in-vehicle motion-sickness study with 31 subjects, where the time-course motion sickness developments of video-watching, book-reading, and normal riding conditions were compared. The results indicate that video-watching brings on 2.7 times more severe motion sickness than normal riding, but 25% less severe than book-reading.



## 1. Introduction

Recent advancement of video-screen technology allows us to watch videos in moving vehicles such as cars, boats, and airplanes. An important issue in the development of in-vehicle video systems is to understand how easily and severely passengers get motion sickness. It is well known that reading books or maps in a moving vehicle brings on and aggravates motion sickness. This is known to be the result of sensory conflict [1], that is, the vestibular system conveys sensory information of body movement, while the visual system conveys stationary information creating the sensation of the body being immobile.

Watching a video in a moving vehicle is considered to trigger sensory conflict in the same manner as book-reading [2]. Schoettle and Sivak [3] investigated the frequency and the severity of motion sickness experienced from in-vehicle video usage by a questionnaire survey. The study indicated that video watching in a moving vehicle caused motion sickness less often than book-reading, but more often than normal riding. Kato and Kitazaki [4,5] also investigated the influence of in-vehicle video display on carsickness by their experimental studies. It showed that reading still images (news text) or watching moving images brought on more severe carsick than the case that passengers were allowed to see external view.

In order to offer comfortable video-watching in moving vehicles, it has been desired to develop new video systems that can reduce motion sickness. For developing such new video systems, it is essential to establish an experimental protocol that can quantitatively evaluate how motion-sickness is developed during

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car-driving. To assess the severity of sickness in series during an experimental trial, it must be briefly evaluated in an instant at every measuring time. A variety of subjective rating methods [e.g., 4–7] and magnitude estimation methods [8] have been frequently used for that purpose. Short Symptoms Checklist [9] is also adopted for evaluating the severity of symptoms at given intervals (e.g., every 5 min) during stimulus periods. Another estimation method, in which subjects respond with a joystick instead of replying with numerical ratings, has been used for continuous measurement [10]. In this paper, we first introduce an experimental protocol and a statistical analysis procedure for quantitative assessment of time-course motion sickness development. Then we demonstrate with a working experimental study that our new approach is practically useful for understanding how motion-sickness is developed during car-driving.

In the experimental protocol, motion sickness is induced to subjects by requiring them to watch a video via an in-vehicle video display during 15-min driving along a winding road. The time-course development of motion sickness is recorded by asking subjects to evaluate their degree of motion sickness every one minute of 15-min driving. The degree of motion sickness is subjectively evaluated with 11 grades (0–10) on a rating scale, which is essentially the same as the well-being score introduced by Reason and Graybiel [11].

One of the difficulties in experimental studies on motion sickness is how to incorporate the individual difference in motion sickness susceptibility which differs markedly among individual subjects. When different stimulus conditions are compared such as video-watching, book-reading, and normal-riding, subjects who have similar susceptibilities should be evenly assigned to each stimulus condition. In some previous studies (e.g., [4–6]), individual susceptibilities are scored by questionnaire such as the Motion Sickness Susceptibility Questionnaire (MSSQ) [12,13] in advance, and the subjects were evenly assigned to each stimulus condition based on the score. However, since motion-sickness susceptibilities are markedly different among individuals, stratification based on questionnaire score is not reliable enough, and the results highly depend on subject assignments.

Therefore, it is desirable that every stimulus condition is evenly tested by each subject (within-subject design). In practice, however, it is difficult to carry out the complete set of trials, i.e., same number of trials with every stimulus condition by each subject. It is because subjects are allowed to withdraw from the subsequent series of trials in accordance with ethical requirement (subjects who had severe motion sickness in the previous trial would not be willing to try it again). As the result, the within-subject design table inevitably has several missing entries. Even worse, those missing entries arise with bias because subjects who have more severe motion sickness tend to withdraw more often than those who have no motion sickness. This kind of practical problem is a formidable issue more or less common to experimental motion-sickness study.

To handle this incomplete data issue, we introduce a simple statistical model for time-course development of motion sickness. This approach allows us to estimate and impute the missing entries in the within-subject design table, and to compare the motion sickness severities among different stimulus conditions. In this paper, for the purpose of demonstration, we conducted an in-vehicle motion-sickness study with 31 subjects, where the time-course motion sickness developments of video-watching, book-reading, and normal riding conditions were compared. The conclusion of the analysis was consistent with previous studies [3–5], i.e., video watching brings on more severe motion sickness than normal riding, but is less severe than book-reading.

## 2. Experimental protocol

In this section, we present the experimental protocol by describing the experimental setup of our working example study on time-course motion sickness.

### 2.1. Subjects

$N = 31$ subjects (21 males and 10 females), approximately 20 years of age, participated in the experiment. None of the subjects reported any medical problems and all presented with normal vestibular functions. Every subject was briefed on the purpose, procedures, risks, and benefits of the study, and gave written informed consent before participating in the experiment. It was also explained that the subjects could withdraw from the experiment whenever they requested, that is, when they could no longer endure the nausea of motion sickness, they could immediately get out of the car and terminate the experimental trial. The experimental protocol used in this study was approved by the Ethics Committee of the Faculty of Engineering, Mie University.

### 2.2. Apparatus

The experiment was performed using a minivan, which had three rows of seats and a boarding capacity of 7 persons. Subjects, one or two in each experimental trial, were seated in the second row of the car. Two in-vehicle video displays were installed separately behind head rests of the first row of the seats by means of the arms fixed to the side roof. They were located about 60 cm apart in front of the individual subjects. The displays had an 11 inch-type wide LCD panel, 244 mm (width) $\times$ 138 mm (height), whose resolution was 800 (horizontal) $\times$ 480 (vertical) pixels. The horizontal and vertical viewing angles for the subjects were about 23 and 13 degrees, respectively. Movies were played on the in-vehicle video displays using a DVD player. Sound was provided by speakers attached on the side doors through an FM radio.

### 2.3. Stimuli (riding conditions and driving course)

The experiment was performed to compare the effect of riding conditions on motion sickness. Subjects rode in the car for $T = 15$ min under one of the following $K = 3$ conditions: (1) video-watching, (2) book-reading, and (3) no-task conditions. Under the video-watching condition ($k = 1$), subjects were required to watch a movie shown on the in-vehicle video displays. The movies used in the experiment did not include any scenes of an intense nature or uncomfortable scenes. They were selected from among romantic and family comedies (“Legally Blonde”, etc.) that had not been watched by the subjects, so that the subjects could concentrate their attention on the scene. The sound was provided in the native language of the subjects (i.e., Japanese) and subtitles were not superimposed. Under the book-reading condition ($k = 2$), subjects were required to read a picture book (“Where’s Wally?”) that had few letters but lots of small fine figures. The task for readers was to look for one or several particular figures which got mixed in among lots of similar ones on each page. In the no-task condition ($k = 3$), subjects were simply asked to remain still and quiet. They were allowed to look outside of the car freely. To ensure the subjects obeying the instructions, their behavior was observed by an experimenter seated in the third row of the car.

The driving course used in the experiment was a suburban road with numerous curves and occasional gentle slopes. It had no traffic signals but two stops. There were no houses along the road, and the traffic, if any, was not heavy. The driving course was a 2.1-km circuit, and it took 3 min to drive around. The car went around the course 5