Can Passengers’ Active Head Tilt Decrease the Severity of Carsickness? Effect of Head Tilt on Severity of Motion Sickness in a Lateral Acceleration Environment

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Objective: We investigated the effect of the passenger head-tilt strategy on the severity of carsickness in lateral acceleration situations in automobiles.

Background: It is well known that the driver is generally less susceptible to carsickness than are the passengers. However, it is also known that the driver tilts his or her head toward the curve center when negotiating a curve, whereas the passenger’s head moves in the opposite direction. Therefore, we hypothesized that the head-tilt strategy has the effect of reducing the severity of carsickness.

Method: A passenger car was driven on a quasi-oval track with a pylon slalom while the participant sat in the navigator seat. The experiment was terminated when either the participant felt the initial symptoms of motion sickness or the car finished 20 laps. In the natural head-tilt condition, the participants were instructed to sit naturally, to relax, and not to oppose the lateral acceleration intentionally. In the active head-tilt condition, the participants were asked to tilt their heads against the centrifugal acceleration, thus imitating the driver’s head tilt.

Results: The number of laps achieved in the active condition was significantly greater than that in the natural condition. In addition, the subjective ratings of motion sickness and symptoms in the active condition were significantly lower than those in the natural condition.

Conclusion: We suggest that an active head tilt against centrifugal acceleration reduces the severity of motion sickness.

Application: Potential applications of this study include development of a methodology to reduce carsickness.

Keywords: motion sickness, carsickness, automobile, head-tilt strategy, ride comfort, vehicle motion
severity of motion sickness. For example, Fujisawa, Wada, Kamiji, and Doi (2009) demonstrated a result that implied that the driver’s head tilt toward the centripetal direction has a correlation with the lateral acceleration while driving on a curve. Golding, Mueller, and Gresty (2003) investigated the difference in the severity of motion sickness with different head movements in a longitudinal acceleration condition aligned and misaligned with the gravito-inertial force (GIF) in active and passive situations, with the assumption that the GIF has a critical effect on motion sickness. In addition, Golding, Markey, and Stott (1995) investigated the effect of motion direction and body postures, such as upright and supine, on motion sickness. They found that motion sickness increased when the body axis was aligned with the direction of acceleration.

In addition, from the theoretical viewpoint of the mechanism of motion sickness, Wada, Fujisawa, Imaizumi, Kamiji, and Doi (2010) previously demonstrated that the estimated motion sickness incidence attributable to the driver’s head motion was less frequent than that attributable to the passenger’s head motion by using the mathematical model of motion sickness proposed by Kamiji, Kurata, Wada, and Doi (2007). The mathematical model was based on the subjective vertical conflict (SVC) theory, which hypothesizes that motion sickness occurs because of the integration of the discrepancy between the vertical direction of the earth estimated from sensory information and the estimated value calculated by the internal model built in the cerebellum (Bles, Bos, De Graaf, Groen, & Wertheim, 1998). The mathematical model by Kamiji et al. is an expanded version of the mathematical model proposed by Bos and Bles (1998) for 6-degrees-of-freedom head motion including head rotation.

Given the findings from the previous literature, we hypothesized that the driver’s head movement against the centrifugal direction has an effect in reducing motion sickness. Furthermore, from the viewpoint of the reduction of passengers’ motion sickness, we hypothesize that a passenger’s active head motion that imitates the driver’s head tilt against centrifugal acceleration has the effect of decreasing the severity of motion sickness. The purpose of the present article is to examine this hypothesis. Thus, this article investigates the effect of the passenger’s active head tilt on the severity of motion sickness in lateral acceleration situations by conducting experiments with a real passenger car. It is expected that the results can provide a basic knowledge for establishing vehicle design and control to minimize motion sickness or to increase comfort.

**METHOD**

**Design**

The experimental design was mainly based on the work of Golding, Bles, Bos, Haynes, and Gresty (2003). For this study, 10 participants were exposed to an acceleration stimulus as passengers seated in the automobile navigator seat. Each participant made head motions in either the aforementioned natural or active condition. In the natural condition, the participants were instructed to sit naturally, to relax, and not to oppose the lateral acceleration intentionally. An experimenter sat in the rear seat and asked the participant to be more relaxed (“natural”) if the participant tilted his or her head against the centrifugal acceleration as much as the driver did. In the active condition, the participants were asked to tilt their head against the centrifugal acceleration, thus imitating the driver’s head tilt. Figure 1 illustrates the typical head postures in the natural and the active conditions. However, the participants were not instructed on the amplitude or the timing of the head tilt.

The head-tilt condition was treated as a within-subject factor. Each participant experienced two head-tilt levels on 2 days at least 3 days apart in a crossover design. The order of the conditions was counterbalanced to remove the order effect. In addition, each participant attended the experiments at the same time on the 2 days if possible, but the experiment days were determined by the participants’ schedules. The experiments involved two drivers. Each participant was assigned to the same driver on both experiment days.

**Participants**

For these experiments, 10 healthy individuals, 9 males and 1 female, with a mean age of 21.5 years ($SD = 1.0$) gave informed consent to
participate. The participants were told that they could become motion sick and vomit because of the experiments. The explanation given to the participants also stated that they could stop the experiment at any time and for any reason. Of the participants, one had already experienced carsickness on the way to the experimental course. The participant confessed so after the experiments. Thus, the results for that participant were not analyzed. The participants were paid approximately $110 for their participation. Before the experiments, the motion sickness susceptibility of each participant was tested with a revised version of the Motion Sickness Susceptibility Questionnaire (Golding, 1998). The mean percentile score was 54.2% (SD = 26.3%). This result illustrates that the susceptibility to motion sickness of the participants had a wide distribution.

For female individuals, it has been found that the menstrual cycle affects their susceptibility to motion sickness (Grunfeld, Price, Goadsby, & Gresty, 1998). We treated the data for the female participant the same as for the males because the female participant was neither in the most susceptible time (around menstruation, at Days 3 to 7 and Days 25 to 27) nor in the least susceptible time (around ovulation, Days 11 to 15).

Method of Evaluating Motion Sickness

We carried out subjective evaluations and symptom score tests to evaluate the severity of motion sickness.

For the subjective evaluations, the subjective sickness rating method used in the research studies of Golding et al. (1995, 2003) was employed. In this method, the severity of motion sickness was rated by a Likert-type scale on the following six levels: 1 = no symptoms, 2 = initial symptoms but no nausea, 3 = mild nausea, 4 = moderate nausea, 5 = severe nausea, and 6 = vomiting. In the present article, the method is referred to as the “six-level sickness rating.” This method is suitable for the real-time rating of motion sickness because the ratings can be determined easily and in a very short time. At the end of every lap in the experiments, the experimenter sitting in the rear seat asked the participants to give their current state according to the six-level sickness rating. In addition, the participants were also asked to declare whether they felt any symptom of motion sickness at any time during a lap. A rating indicating motion sickness triggered the termination of that driving trial.

The symptoms of motion sickness were quantified by a motion sickness symptom score test (Golding et al., 1995) administered approximately 5 min and 10 min after the termination of the driving test. The score test quantifies the symptoms of motion sickness, rated subjectively by the participants using four levels of 0 = none, 1 = mild, 2 = moderate, and 3 = severe for each symptom of dizziness, body warmth, headache, sweating, stomach awareness, increased salivation, nausea, pallor (evaluated by the experimenter), and any additional symptoms. We calculated the total symptom score by summing the ratings to quantify the severity of motion sickness (Golding et al., 1995).

Apparatus

A small passenger car with a 2.37-m wheel base and a 1,000-cc engine was used for the driving experiments. An MTi-G sensor (Xsense Technologies) was attached to a flat place close to the shift lever of the automatic transmission to measure the 3-degrees-of-freedom acceleration and the 3-degrees-of-freedom orientation of the vehicle (Figure 2). An MTx sensor (Xsense Technologies) was attached to the cap worn by the participants to measure the 3-degrees-of-freedom acceleration and the
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3-degrees-of-freedom orientation of the head (Figure 2). Both sensors were connected to a laptop PC in the rear seat of the vehicle to synchronize the sensor data. The sampling time for the two sensors was 10 ms.

Procedure

As stated earlier, the participants gave written informed consent before the experiments. Each participant was seated in the navigator seat of a small passenger car in a normal seating position with a safety belt and then was exposed to the acceleration applied by the driver. The experimental course was a quasi-oval track with straight parts approximately 100 m in length and curved parts of 8 m and 10 m radii (Figure 3). Located in each straight segment were five pylons with 15-m gaps. The driver drove the track continuously at approximately 30 km/h through the pylon slalom (i.e., zigzagging to the left and right of the pylons) in the straight segment and at approximately 15 km/h in the curved segments. The track distance was 260 m. The resultant mean lap time and mean total exposure time for 20 laps were 45 s and 14 min 46 s, respectively. The drivers were aware of the head-tilt conditions.

We compared the mean frequency of lateral oscillation frequencies in the slalom part and the root mean square (RMS) vehicle lateral accelerations in the head-tilt conditions to verify the uniformity of the stimulus. The means and standard deviations of the resultant lateral oscillation frequencies in the natural and active conditions were 0.238 Hz ($SD = 0.02$) and 0.237 Hz ($SD = 0.02$), respectively. The mean frequencies were in the frequency range (around 0.2 Hz) that most provoke sickness (Golding et al., 2001). No significant differences were found in the lateral oscillation frequencies by the repeated-measures ANOVA, $F(1, 15) = 0.082, p = .778$. The RMS vehicle lateral accelerations in the natural and active conditions were 2.40 m/s$^2$ ($SD = 0.18$) and 2.42 m/s$^2$ ($SD = 0.19$), respectively. No significant differences were found in the RMS vehicle accelerations by the repeated-measures ANOVA, $F(1, 7) = 0.024, p = .881$. Note that the vehicle acceleration data were analyzed for only 8 participants because of the misrecording of the vehicle data of 1 participant in addition to the participant who was not analyzed because of his poor health.

At the end of each lap, the experimenter asked the participants to indicate their severity of motion sickness according to the six-level sickness rating used in the research studies of Golding et al. (1995, 2003). The participants were also asked to declare whether the six-level sickness rating reached 2 or higher at any time during a lap. When Level 2 or higher was
experienced, the driving trial was terminated at the end of the next lap. Note that the participants were told again at that time that they could stop immediately without this additional lap, but no participant rejected the additional lap. Each driving trial was terminated after 20 laps, the maximum number of laps even if the subjective rating did not reach 2 or higher. The time of termination is called the driving endpoint.

RESULTS

Resultant Head Movement

Figure 4 presents an example of the time history of the vehicle lateral acceleration and the head tilt. The head-roll angle, defined as the orientation of the head in the frontal plane, was used for evaluation of the head-tilt behavior of the participants. In the natural condition, passive head movement toward the centrifugal direction was found with a time delay. A small head roll without synchronization with the lateral acceleration was also found in the natural condition (no figure). In the active condition, the head-roll angle was found to synchronize with the vehicle lateral acceleration.

The correlation coefficients between the vehicle lateral acceleration and the head-roll angle throughout the experiment were analyzed. The means and standard deviations of the correlation coefficients for all participants in the natural and the active conditions were 0.43 (SD = 0.30) and −0.71 (SD = 0.10), respectively. The positive correlation coefficient represents that the head-roll motion synchronized well with the vehicle lateral acceleration in the centrifugal direction. Thus, a high negative correlation was found in the active condition, whereas a lower positive correlation was found in the natural condition. A Wilcoxon signed-rank test revealed the significance between the head-tilt conditions (z = −2.52, n = 8, ties = 0; p = .0117, two tailed): The head-roll angle in the active condition was greater in the centripetal direction, whereas that in the natural condition was made in the opposite direction at lower synchronization with the vehicle motion. This result is consistent with the tendency of the passenger’s and driver’s head-roll angles in Konno et al. (2010).

Laps to Driving Endpoint

The means and standard deviations for the number of laps of the driving endpoint for all participants in the natural and the active conditions were 13.7 laps (SD = 5.6) and 17.9 laps (SD = 3.1), respectively. We used the Wilcoxon signed-rank test to analyze the differences. Some participants recorded 20 laps in both head-tilt conditions. To break ties, we weighted the number of laps using the total symptom score recorded 5 min after the experiments by adopting the method of Golding et al. (1995). The Wilcoxon signed-rank test was used for statistical test because of the abnormal distribution of the data, which came from the termination of driving at 20 laps. The Wilcoxon test (with the weighting) revealed significant differences in the number of laps based on the head-tilt condition (z = −2.53, n = 9, ties = 1; p = .011, two tailed). The active condition had a larger number of laps to the driving endpoint. We analyzed the data of the male participants by excluding the female participant’s data with the Wilcoxon signed-rank tests (with the weighting). The results also revealed significant differences in the number of laps.
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Laps based on the head-tilt condition ($z = -2.38$, $n = 8$, ties = 1; $p = .018$, two tailed).

### Six-Level Sickness Rating at Driving Endpoint

Table 1 shows the number of participants experiencing each sickness rating level at the driving endpoint. No participant experienced Levels 4 through 6 in the experiments. In the natural condition, 5 participants experienced Level 3, and in the active condition, 6 participants experienced no symptoms. We analyzed the data of the male participants by excluding the female participant’s data with the Wilcoxon signed-rank tests. The results also revealed significant differences in the sickness rating levels between the head-tilt condition ($z = -2.07$, $n = 8$, ties = 3; $p = .038$, two tailed).

The Wilcoxon signed-rank test revealed a significant difference in the sickness rating levels between the head-tilt conditions ($z = -2.27$, $n = 9$, ties = 3; $p = .023$, two tailed). The six-level sickness rating in the active condition was lower than that in the natural condition.

### Total Symptom Score

Figure 5 illustrates the transition of the total symptom scores for both head-tilt conditions. The Wilcoxon signed-rank test revealed a significant difference in the symptom scores between the head-tilt conditions 5 min after driving termination ($z = -2.56$, $n = 9$, ties = 1; $p = .011$, two tailed). The scores in the active condition were lower than those in the natural condition. A significant difference also appeared between the head-tilt conditions 10 min after driving termination ($z = -2.12$, $n = 9$, ties = 3; $p = .034$, two tailed). We analyzed the data of the male participants by excluding the female participant’s data with the Wilcoxon signed-rank tests. The results also revealed significant differences in the symptom scores between the head-tilt conditions 5 min after driving termination ($z = -2.39$, $n = 8$, ties = 1; $p = .017$, two tailed) and 10 min after driving termination ($z = -2.12$, $n = 8$, ties = 3; $p = .034$, two tailed).

### DISCUSSION

The increase in the number of laps to the driving endpoint and the reduction of the six-level sickness rating and the total symptom scores indicate the effect of the active head-tilt condition in reducing motion sickness. These results suggest that the carsickness of passengers can be reduced if they tilt their head against the centrifugal direction, thus imitating the driver’s head tilt.

This finding agrees with the results from Golding et al. (2003), in which the severity of motion sickness decreased when the head was aligned with the GIF in a longitudinal linear acceleration environment in the active head movement of the participant. The contribution of the present article is to demonstrate the effect of head tilt on reducing the severity of motion sickness in a real automotive environment with visual information of upcoming road shape during lateral acceleration. In addition, the amplitude of the head movement in the present study was not instructed, and the head-tilt angle was smaller than that aligned with the GIF. The findings of the present article are consistent with the hypothesis presented by Fukuda (1976) on the
basis of observation of the head movements of bus drivers and their passengers.

Rolnick and Lubow (1991) reviewed in detail the literature relating to immunity from motion sickness in drivers from the viewpoint of factors of head movement, visual information, perceived control, activity, predictability, and controllability. Among these factors, visual information, perceived control, predictability, and controllability were equivalent through the experiments in the present study. The visual information was not very different between the two head-tilt conditions, because participants sat in the navigator seat and observed the road scene ahead. A perceived control or sense of control is a subjective psychological state by which the person can determine his or her behavior. The factor of perceived control was also equivalent in both head-tilt conditions because the participants made their head motions by themselves and had been informed that they could stop the experiment at any time. The predictability factor was also equivalent because the participants watched the same scene and rode along a predetermined test track.

With regard to the controllability factor, Rolnick and Lubow (1991) showed that participants who felt themselves in control were less likely to get motion sickness. In their article, a passive participant with no controllability of vehicle motion was also prevented from moving his or her head voluntarily by being “yoked” to the other (active) passenger’s head. The present article reveals that motion sickness can be reduced by a voluntary head tilt toward the GIF direction without any controllability of vehicle motion in the condition in which visual information of upcoming road curve is available. Activity is also a factor related to motion sickness, as Wendt (1951) postulated, whereas Rolnick and Lubow pointed out that very few studies directly indicated the effect of this factor, and one study demonstrated contradictory results. In the present study, activity is relatively greater in the active head-tilt condition than in the natural condition, since in the active condition, the participant needs to control his or her head according to the lateral acceleration changes. The fact that the activities in the two head conditions were not the same is a limitation of the present study. It is thought, however, that the difference was not very large because appropriate postural control, including head control, was needed even in the natural head-tilt condition.

Another possible interpretation of the reduction effect of motion sickness is difference between active and passive head movements in the head-tilt condition. According to the reafference principle (von Holst, 1954), adaptation is promoted in the case of active movement by comparing the efference copy of the motor command and the reafference from the effector. Held and Bossom (1961) showed that prism adaptation was significantly faster in the self-produced motion or active condition. Namely, it can be understood that rearrangement in the sensory rearrangement theory (Reason & Brand, 1975) was accelerated in active movements. The active and natural conditions in the present article are regarded as active and passive movements of the head, respectively. Therefore, the reduction effect of motion sickness can be partially interpreted as the effect of active movement.

It should be noted again, however, that Golding et al. (2003) showed that level of motion sickness when head motion aligned with GIF direction was significantly lower than that with misaligned head motion even though both head movements are actively produced. This result can be understood as that head movement itself has the effect of reducing motion sickness. To clarify the pure effect of the head tilt of the passenger, experiments with different head conditions, including misaligned with GIF direction, should be conducted as a future research study.

Bles et al. (1998) proposed an SVC theory as the mechanism of motion sickness and postulated that motion sickness is caused by accumulation of the discrepancy between the vertical direction sensed by the sensory organs, such as the eyes, the vestibular system, and nonvestibular proprioceptors, and the subjective vertical direction estimated from the internal model. Wada et al. (2010) found that a head tilt toward the curve center has the effect of reducing the incidence of motion sickness by using the mathematical model based on the SVC theory derived by Kamiji et al. (2007), which is a
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6-degrees-of-freedom version expanded from the original 1-degree-of-freedom version by Bos and Bles. (1998). The result of the SVC model calculation, in which head movement toward the curve center reduces the incidence of motion sickness, agreed with the experimental results of the present article. In the calculation of both the active and the passive condition, only head movements are changed even though the 6-degrees-of-freedom SVC model includes the parameters reflecting efference copy. Thus, it is understood that a head tilt close to the GIF direction results in a reduction of the conflict with the subjective vertical direction. Thus, the results presented in this article can be understood as the reduction of motion sickness in the sense of SVC theory.

CONCLUSION

An experiment was conducted to examine the hypothesis that a passenger’s head tilt that imitates a driver’s active head-tilt strategy against centrifugal acceleration in an automobile during lateral acceleration reduces motion sickness. The results showed that the mean number of laps before any symptoms was significantly larger in the active head-tilt condition. In addition, the six-level sickness rating at the driving endpoint in the active head condition, as well as the total symptom score in the active head condition, was significantly reduced. These results strongly indicate that a passenger’s active head tilt toward the centripetal direction has the effect of reducing the severity of motion sickness during the lateral acceleration of an automobile.

As a topic for future study, it is important to investigate whether the conclusions are derived for females and a wide range of age groups, because the present study investigated only young people and only one female. In addition, the effects of various head motions on motion sickness, including the timing and magnitude of any head tilt, should be investigated in detail. These investigations would lead to basic knowledge for developing a methodology to reduce motion sickness. Experiments with a fixed-head condition should be conducted to investigate the pure effect of head movement. Furthermore, a comparison between eyes-open and eyes-closed conditions would be beneficial to further investigate the basic mechanism of carsickness.

KEY POINTS

- In comparison with the natural head-tilt condition, the active head tilt of a passenger in a lateral acceleration environment in an automobile significantly increased the number of laps before the passenger experienced the initial symptom of motion sickness.
- The active head-tilt condition significantly reduced the six-level sickness rating and the total symptom score after the driving trials.
- These results strongly indicate that a passenger’s active head tilt toward the centripetal direction has the effect of reducing the severity of motion sickness during lateral acceleration of an automobile.

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