Reduction of Carsickness using a Headrest with Support to Suppress Head Motion

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ABSTRACT

There are growing concerns about increasing carsickness in a self-driving car as drivers perform various non-driving tasks during autonomous driving. It would appear that reducing motion of the head where the vestibular and the visual systems locate effectively reduces carsickness. Hence, we developed a novel headrest with occipital bone support (OBS) that could suppress passengers' head motion and examined its effectiveness on carsickness. In the experiment, participants sat in a minivan's second-row seat behind a driver's seat and watched a video on a tablet terminal during a 30-minute vehicle journey on urban roads and reported the carsickness ratings at 1-min intervals. One of four seating conditions (a combination of two seating postures, 'upright' and 'relaxed', and two types of headrests, 'normal' and 'OBS') was examined in each journey. Head and thorax motion was also acquired using wireless motion sensors. Motion Sickness Dose Value (MSDV) was calculated for each axis. The results showed that the developed OBS headrest significantly reduced MSDVs at the head, and the mean accumulated illness ratings for 30 minutes were also significantly reduced by more than 40%.

KEYWORDS

Carsickness, Head motion, Headrest

Introduction

It is known that vehicle drivers rarely get carsickness, but passengers often experience it. It has been reported that vehicle passengers suffer less carsickness when they can see the external forward view and more sickness when the external view is blocked or under reading/video viewing conditions (Griffin and Newman (2004), Kato and Kitazaki (2006, 2008)). Therefore, there are growing concerns about increasing carsickness in a self-driving car as drivers perform various non-driving tasks during autonomous driving (e.g. Diels and Bos (2016)).

Kato and Kitazaki (2006) evaluated the effects of different head and body restraints on head motion and carsickness of the passengers who sat in the second-row seat behind a driver seat and could see the external view. They reported that the increased restraints reduced passengers' low-frequency head motion and carsickness. They also found that the reduction of relative visual motion between passenger's eyes and an in-vehicle display using electric pitch compensation and optical collimation could reduce carsickness. Wada and Yoshida (2016) examined the effects of head tilting in a passenger car where passengers could see the external view through the front window. They found that head-tilt against centrifugal direction decreased passengers' carsickness compared with tilting in the opposite direction.

Hence, we hypothesized that reducing the motion of the head where the vestibular and the visual systems locate could reduce the occurrence of excessive low-frequency acceleration at the head and mitigate carsickness in an internal-view condition.

This paper describes the effects of a newly developed headrest with occipital bone support designed to suppress passengers' head motion on carsickness in a video viewing condition in a moving vehicle.

Methods

Vehicles and Journey

The study was undertaken using a minivan (NISSAN ELGRAND, 2.5L engine type) which had an automatic transmission. The second-row seats of the vehicle were equipped with articulated backrests, which passengers could adjust the reclining angle of the upper and lower backrest individually. A 10.1-inch tablet terminal was attached to the driver's headrest for the participant's visual tasks during the experiment. The distance between the tablet and the participant's eyes was approximately 800 mm, and the height of the tablet screen and the participant's eyes was the same. The vehicle was driven for 30 minutes on urban roads in Yokohama city, where there were many intersections without traffic signals. The driving course was fixed, and the drivers were instructed to drive safely and keep a consistent driving manner in each journey. As described later, the drivers could monitor the real-time vehicle floor MSDVs in fore-aft and lateral direction and adjust the acceleration, braking and cornering.

Motion Measurement

Acceleration (fore-aft, lateral and vertical)) and angular velocity (roll, pitch and yaw) was measured continuously during every journey on the vehicle floor, participant's head and thorax using wireless hybrid sensor WAA-010 (Wireless Technology Co. Ltd., Tokyo, Japan). The angular velocity data was differentiated with respect to time and transformed into the angular acceleration. The linear and angular acceleration was frequency-weighted using W_f frequency weighting and the motion sickness dose valus (MSDVs) defined in ISO2631-1 (1997) were calculated for every journey.

$$MSDV = \left[\int a_w^2\,(t)dt\right]^{1/2}$$

where $a_w(t)$ is the frequency-weighted acceleration.

Though the MSDV and W_f were developed to predict motion sickness caused by vertical motion, we extended them to other directions.

Participants

Eight healthy volunteers participated in the study. All participants were male, aged 19 to 56 yr, and had previously experienced carsickness. They were selected from the employee population of NHK Spring company. They gave their informed consent to participate in the experiment, which was approved by the Ethics Committee of the Seating Division, NHK Spring Co., Ltd.

Illness Rating Scale

Every minute during the journey, participants were asked to rate their illness using a scale from 0 to 6 (0: no symptoms; 1: any symptoms, however slight; 2: mild symptoms, e.g., stomach awareness but not nausea; 3: mild nausea; 4: mild to moderate nausea; 5: moderate nausea but can continue; 6: moderate nausea and want to stop). The journey was terminated if an illness rating of 6 was reached or the full 30-min journey had been completed.

Experimental procedures

Participants were seated in a second-row seat of the test vehicle behind a driver seat and wore a safety belt. They were asked to keep their heads in touch with a headrest during the journey and watch a video on a screen. One of four seating conditions, a combination of the following two seating postures and two types of headrests, was examined in each journey.

1) Sitting postures (Figure 1)
   a) Upright: Normal sitting posture without armrest and leg rest; Backrest angles were 23 degrees (lower) and 19 degrees (upper) from a vertical direction at the backrest surface.
   b) Relaxed: Relaxed posture with armrest and leg rest; Backrest angles were 33 degrees (lower) and 18 degrees (upper) from a vertical direction at the backrest surface.
2) Headrest (Figure 2)
   a) Normal: Normal headrest.
   b) OBS: Headrest with occipital bone support.

(a) Upright

(b) Relaxed

Figure 1: Experimental seat with a normal headrest and seating geometry

Figure 2: Headrest with an occipital bone support

The V-shaped occipital bone support was made from polyurethane foam firmer than foam for a standard headrest. It could support occipital bone's right and left side regardless of passengers' body type and shape of the cranial bone. For safety reasons, the height of the occipital bone support was carefully designed not to overstress the occupant's neck when excessive lateral force acted.

The order of the seating conditions was counterbalanced. Each participant experienced one condition a day and at the same hour each day to prevent the influence of the circadian rhythm.

After the participants experienced all of the four conditions, they were asked to rate how easy it was to watch a video in OBS condition compared to in normal headrest condition using seven-point rating (3: very easy, 2:easy, 1: slightly easy, 0: the same, -1: slightly hard, -2 hard, -3: very hard).

Data analysis

Non-parametric statistical methods were used throughout for data analysis. As all eight participants experienced all four conditions in this study, a matched-pair analysis was applied to compare four conditions. Multiple Comparison Procedure was applied for significant tests. Firstly, p-values for all pairs were calculated using the Wilcoxon signed-rank test (two-tailed). Then the values were adjusted using the Benjamini-Hochberg Procedure to control False Discovery Rate (FDR) (Benjamini and Hochberg (1995)). We employed $q^* = \alpha = 0.05$ for the adjustment.

Statistical data analysis was performed using JMP version 16.0.0 (SAS Institute Inc., Cary, U.S.)

Results

Figure 3 shows the mean illness ratings of eight participants for every minute of the 30-min journey, and Figure 4 shows the accumulated illness ratings for 30 minutes. The results of the Multiple Comparison test is shown in Table 1 (a). Significant differences were found between the three conditions ($p<0.05$). The accumulated illness ratings decreased by 42.2% in the Upright-Normal condition, 50.7% in the Relaxed-OBS condition against the Upright-Normal condition.

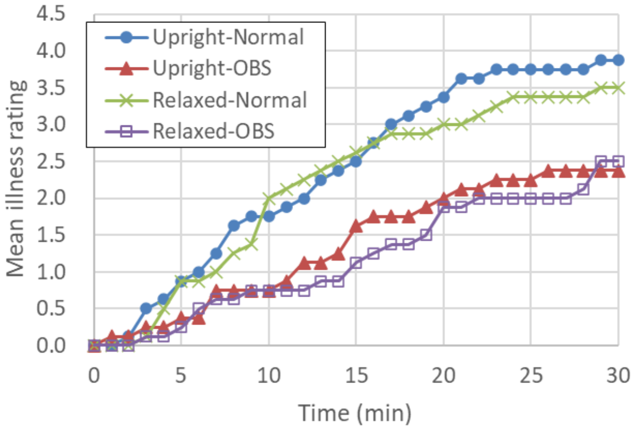


Figure 3: Mean illness ratings during the 30-min journey

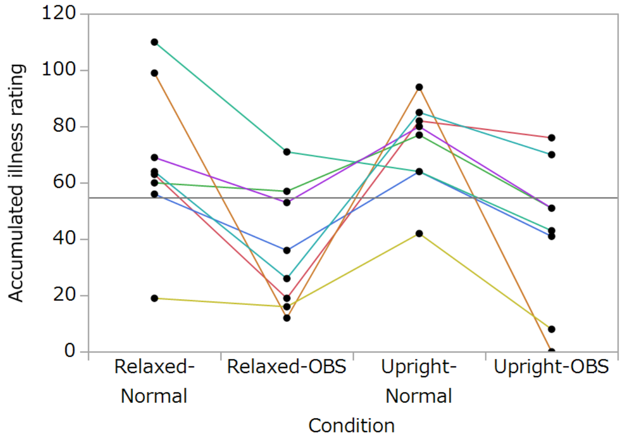
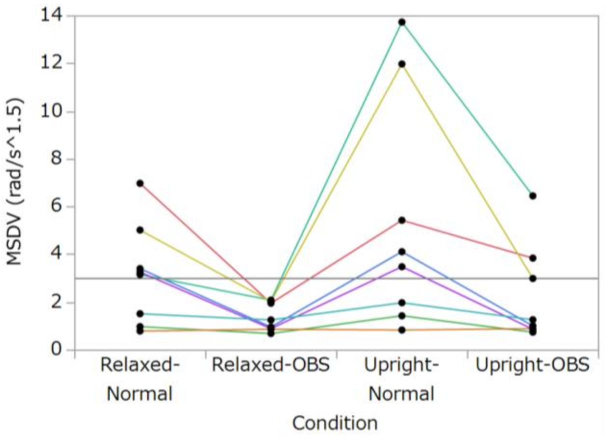
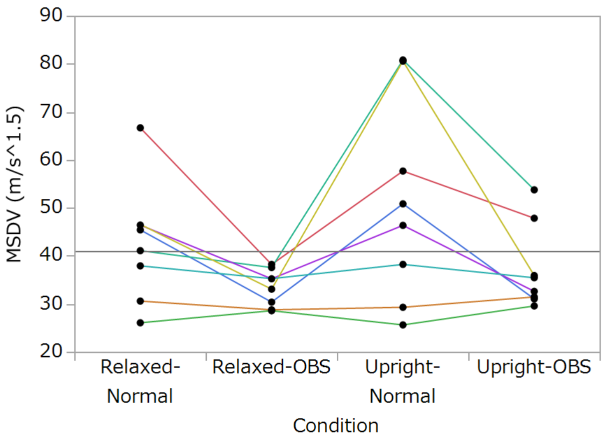


Figure 4: Accumulated illness ratings during the 30-min journey. Lines connect data of the same participant with the same colour.

Figure 5 shows MDSVs in four conditions in head roll and head lateral directions. The results of the Multiple Comparison test showed that there were significant differences between the four conditions in the head roll direction ($p<0.05$; Table 1(b)). The decrease rate of mean MSDVs was 57.9% in the Upright-OBS condition and 75.0% in the Relaxed-OBS against the Upright-Normal condition. In the head lateral direction, only significant trends were found between the four conditions ($p=0.0821$, 0.0702; Table 1(c)). The mean MSDVs reduced by 27.3% in the Upright-OBS conditions and 34.7% in Relaxed-OBS against the Upright-Normal condition. No significant differences were found in the other directions ($p>0.05$). The results of the Wilcoxon signed-rank test on video viewing ease showed that there was a significant difference between OBS and normal headrest conditions ($p<0.05$), and it was found that the OBS was suitable to watch a video in a moving vehicle.



(a) Roll direction



(b) Lateral direction

Figure 5: Comparisons of MSDVs in roll and lateral directions in four conditions. Lines connect data of the same participant with the same colour.

Table 1: Results of Multiple Comparison test between the four conditions.

(a) Accumulated illness ratings

Rank	Pair	p-value	Adjusted p-value
6	Upright-OBS vs Relaxed-OBS	0.9453	0.9453
5	Upright-NML vs Relaxed-NML	0.2500	0.3000
4	Upright-OBS vs Relaxed-NML	0.0781	0.1172
3	Upright-NML vs Relaxed-OBS	0.0156	0.0312*
2	Relaxed-NML vs Relaxed-OBS	0.0078	*
2	Upright-NML vs Upright-OBS	0.0078	*

(b) MSDVs in roll direction

Rank	Pair	p-value	Adjusted p-value
6	Relaxed-NML vs Upright-OBS	0.2500	0.2500
5	Relaxed-NML vs Upright-NML	0.1094	0.1313
4	Relaxed-OBS vs Upright-OBS	0.0234	0.0351*
3	Relaxed-OBS vs Upright-NML	0.0156	*
3	Upright-OBS vs Upright-NML	0.0156	*
3	Relaxed-OBS vs Relaxed-NML	0.0156	*

(c) MSDVs in lateral direction

Rank	Pair	p-value	Adjusted p-value
6	Relaxed-NML vs Upright-NML	0.6406	0.6406
5	Relaxed-NML vs Upright-OBS	0.2500	0.3000
4	Relaxed-OBS vs Upright-OBS	0.0547	0.08205 †
4	Upright-OBS vs Upright-NML	0.0547	0.08205 †
2	Relaxed-OBS vs Upright-NML	0.0234	0.0702 †
2	Relaxed-OBS vs Relaxed-NML	0.0234	0.0702 †

(*: $p<0.05$, † : $p<0.10$)

Discussion

As Figure 4 indicates, all participants assigned a headrest with OBS with lower illness scores than a normal headrest in the sitting posture. However, the MSDVs in roll and lateral directions didn't show such unanimous results though significant differences and trends were found. On the other hand, the differences in the illness ratings between with and without OBS were consistent with those of the predicted motion sickness incidences in different head movement conditions calculated using a six-degree-of-freedom head motion model (Wada et al., (2018)). These suggest that carsickness in video viewing condition is not induced solely by the roll or lateral head motion but by complex six-degree-of-freedom head motion and relative motion between passenger's eyes and a display and other factors such as somatosensor.

Regarding the video viewing ease in a moving vehicle, the participants commented that they considered the OBS better than the normal headrest because the former suppressed head yaw motion relative to a headrest and made it easier to glance toward a display. However, differences in MSDVs in yaw direction between the OBS and normal headrest conditions were not statistically significant. It appears that rapid head yaw movement during cornering was not included in calculated MSDVs as the upper cut-off frequency used to calculate MSDV was set at 0.68Hz and resulted in such inconsistency.

Conclusions

The effects of a developed headrest with occipital bone support (OBS) on carsickness were examined in a field study. The results showed that the OBS effectively reduced occupants' low-frequency head motion and mitigated carsickness significantly compared to a normal headrest. It was also found that the use of OBS improves the video viewing ease on an in-vehicle display. The results suggest that the simply structured OBS headrest can be low-cost and effective measures to reduce carsickness in passenger vehicles, including a self-driving car in which an increase in carsickness is concerned.

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