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MOTION SICKNESS IN SELF-DRIVING VEHICLES

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16. Abstract

Motion sickness is expected to be more of an issue in self-driving vehicles than in conventional vehicles. The reason is that the three main factors contributing to motion sickness (conflict between vestibular and visual inputs, inability to anticipate the direction of motion, and lack of control over the direction of motion) are elevated in self-driving vehicles. However, the frequency and severity of motion sickness is influenced by the activity that one would be involved in instead of driving.

This report calculates the expected frequency and severity of motion sickness in fully self-driving vehicles based on the expected frequencies of different activities from a recent survey of what individuals would be likely to do in a fully self-driving vehicle—a survey performed in the U.S., China, India, Japan, the U.K., and Australia. The results indicate that, for example, 6%-10% of American adults riding in fully self-driving vehicles would be expected to often, usually, or always experience some level of motion sickness. Analogously, 6%-12% of American adults riding in fully self-driving vehicles would be expected to experience moderate or severe motion sickness at some time. Calculations for the other five countries are also presented.

The report concludes with a discussion of ways to minimize the frequency and severity of motion sickness in self-driving vehicles.

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Introduction

In the current debate about self-driving vehicles, one important topic that has not received sufficient attention is motion sickness, although a recent review by Diels (2014) is a notable exception. This topic is important because there are several aspects of alternative activities in self-driving vehicles that increase the susceptibility to motion sickness. This report discusses the activities that adults are likely to be involved in while riding in fully self-driving vehicles based on a recent survey in six countries (Schoettle and Sivak, 2014), and calculates the effects of these activities on the frequency and severity of motion sickness.

Basic aspects of motion sickness

Motion sickness (kinetosis) is a condition marked by symptoms of nausea, dizziness, and other physical discomfort. (The name for the primary symptom—*nausea*—is a Latin word derived from the Greek *nausia*, both meaning "seasickness.") More extreme symptoms can include vertigo and vomiting. Adults are more susceptible to motion sickness than are children (Reason and Brand, 1975). Comprehensive reviews of motion sickness are contained in Reason and Brand (1975) and Benson (2002).

Motion sickness most often results from a sensory conflict between inputs from the visual and vestibular systems (Reason and Brand, 1975). The environments in which we experience these circumstances can be found in various modes of transportation (e.g., passenger vehicles, boats, and planes) and in common entertainment and leisure activities (e.g., amusement park rides, video games, and 3D movie theaters).

Although motion sickness is most frequently caused by a conflict between visual and vestibular inputs, loss of control over one's movements (Rolnick and Lubow, 1991) and reduced ability to anticipate the direction of movement (Golding and Cresty, 2005) are also important in the etiology of motion sickness. All three factors, to varying degrees, are more frequently experienced by vehicle passengers than by drivers, who rarely experience motion sickness (Reason and Brand, 1975).

In turn, the extent of visual input, the direction of gaze, and posture have strong influences on the degree of conflict between vestibular and visual inputs, and on the ability to anticipate the direction of movement (see Table 1).

Table 1
Contributing aspects that influence the impact of the critical factors for motion sickness. A negative effect **(-)** indicates a worsening of motion sickness, while a positive effect **(+)** indicates an improvement.

Contributing aspect	Critical factor		
	Conflict between vestibular and visual inputs	Ability to anticipate the direction of movement	Control over the direction of movement
Extent of visual input	• narrow or small windows (-) • opaque or reduced-visibility windows (-) • no conflict when having the eyes closed or sleeping (+)	• narrow or small windows (-) • opaque or reduced-visibility windows (-)	Not relevant for passengers
Direction of gaze	• non-forward gaze (-)	• non-forward gaze (-)	Not relevant for passengers
Posture	• side or rear facing (-) • supine (+)	• side or rear facing (-)	Not relevant for passengers

What passengers would do in fully self-driving vehicles

In a recent opinion survey concerning self-driving vehicles, we included a question about what people would do instead of driving in a fully self-driving vehicle (Schoettle and Sivak, 2014). The study included responses from 3,255 adults in the U.S. and five other countries (China, India, Japan, the U.K., and Australia). The complete results for this question are shown in Table 2.

The results indicate that 23% of American adults would not ride in a self-driving vehicle. The corresponding percentages in the other countries were 3% in China, 8% in India, 21% in Australia, 23% in the U.K., and 33% in Japan.

Table 3 presents recalculated percentages for the different activities if those who would not ride in self-driving vehicles are excluded.

Table 2
Percentages of responses to the question "If you were to ride in a completely self-driving vehicle, what do you think you would use the extra time doing instead of driving?"
(Adapted from Schoettle and Sivak, 2014.)

Response	U.S.	China	India	Japan	U.K.	Australia
I would not ride in a self-driving vehicle	23.0	3.1	7.8	33.0	23.0	21.2
Watch the road even though I would not be driving	35.5	36.1	30.7	33.2	44.0	43.4
Read	10.8	10.5	10.2	5.6	7.6	6.5
Text or talk with friends/family	9.8	20.8	15.0	7.4	5.5	7.9
Sleep	6.8	10.8	4.7	12.6	7.2	7.1
Watch movies/TV	6.0	11.3	12.3	6.2	4.2	5.7
Work	4.8	5.4	16.3	0.7	4.9	5.1
Play games	2.0	1.3	2.1	1.2	1.9	2.0
Other	1.4	0.7	0.8	0.2	1.7	1.0

Table 3
Percentages of responses to the question "If you were to ride in a completely self-driving vehicle, what do you think you would use the extra time doing instead of driving?"
Those who would not ride in self-driving vehicles were excluded.
(Adapted from Schoettle and Sivak, 2014.)

Response	U.S.	China	India	Japan	U.K.	Australia
Watch the road even though I would not be driving	46.1	37.2	33.3	49.5	57.1	55.0
Read	14.0	10.8	11.1	8.4	9.9	8.3
Text or talk with friends/family	12.7	21.5	16.3	11.0	7.1	10.1
Sleep	8.8	11.2	5.1	18.9	9.4	9.0
Watch movies/TV	7.8	11.7	13.4	9.2	5.4	7.3
Work	6.2	5.6	17.7	1.0	6.4	6.5
Play games	2.6	1.4	2.3	1.8	2.5	2.5
Other	1.8	0.7	0.8	0.3	2.2	1.3

Table 4 summarizes the main effects of alternative activities in Table 3 on the three critical functions that influence the frequency and severity of motion sickness.

Table 4
Effects of alternative activities on critical functions that influence the frequency and severity of motion sickness. A negative effect (-) indicates a worsening of motion sickness, while a positive effect (+) indicates an improvement.

Alternative activity while riding in a self-driving vehicle	Critical factor		
	Conflict between vestibular and visual input	Ability to anticipate the direction of movement	Control over the direction of movement
Watching the road	+	+	-
Reading	-	-	-
Sleeping	+	-	-
Texting	-	-	-
Talking on the phone	depends on the direction of gaze	depends on the direction of gaze	-
Watching movies/TV	- especially for downward gaze	- especially for downward gaze	-
Working	- especially for downward gaze	- especially for downward gaze	-
Playing games	- especially for downward gaze	- especially for downward gaze	-

General implications for the frequency and severity of motion sickness

Table 5 presents, for each country, the percentage of adult passengers in fully self-driving vehicles who would, as a group, experience an increase in the frequency and severity of motion sickness. The entries in Table 5 are based on the percentages of adults who would engage in those alternative activities that increase the frequency and severity of motion sickness (Schoettle and Sivak, 2014). The activities that were not included in Table 5 were "sleeping" because of its positive effect on motion sickness, and "watching the road," "talking on the phone," and "other" activities because of their uncertain effects on motion sickness.

Table 5
Percentage of adult passengers in fully self-driving vehicles who would, as a group, experience an increase in the frequency and severity of motion sickness.

Alternative activity that increases the frequency and severity of motion sickness	U.S.	China	India	Japan	U.K.	Australia
Reading	14.0	10.8	11.1	8.4	9.9	8.3
Texting*	6.4	10.8	8.2	5.5	3.6	5.1
Watching movies/TV	7.8	11.7	13.4	9.2	5.4	7.3
Working	6.2	5.6	17.7	1.0	6.4	6.5
Playing games	2.6	1.4	2.3	1.8	2.5	2.5
Total	*37.0*	*40.3*	*52.7*	*25.9*	*27.8*	*29.7*

*Assuming that of the respondents who indicated that they would text or talk with friends/family, 50% would text and 50% would talk.

Estimated frequency and severity of motion sickness in fully self-driving vehicles

In a recent study (Schoettle and Sivak, 2009), we surveyed the frequency and severity of motion sickness while watching video or reading in a moving conventional vehicle. The results for the adult respondents are summarized in Table 6.

Table 6
Frequency and severity of motion sickness for adults while watching video or reading in a moving conventional vehicle. (Adapted from Schoettle and Sivak, 2009.)

Measure	Activity	
	Viewing video	Reading
Frequency: *Often, usually, or always*	15%	26%
Severity: *Moderate or severe*	15%	32%

The information in Table 6 can be used, as a first approximation, to bracket the expected frequency and severity of motion sickness from all activities listed in Table 5 (reading, texting, watching movies/TV, working, and playing games). In Table 7, these brackets (15%-26% often, usually, or always experiencing some level of motion sickness, and 15%-32% experiencing moderate or severe motion sickness at some time) were applied to those percentages of passengers in fully self-driving vehicles who are expected to be involved in the activities in question. As an example, the calculations for the U.S. were as follows:

- Frequency, 15% factor: 37.0 x 0.15 = 6
- Frequency, 26% factor: 37.0 x 0.26 = 10
- Severity, 15% factor: 37.0 x 0.15 = 6
- Severity, 32% factor: 37.0 x 0.32 = 12

Table 7
Percentages of adult passengers in fully self-driving vehicles who are expected to participate in motion-sickness-related activities, and the resultant percentages of adult passengers expected to experience motion sickness.

Aspect	U.S.	China	India	Japan	U.K.	Australia
Expected to be involved in activities that increase the frequency and severity of motion sickness	37.0%	40.3%	52.7%	25.9%	27.8%	29.7%
Would often, usually, or always experience some level of motion sickness	6-10%	6-10%	8-14%	4-7%	4-7%	4-8%
Would experience moderate or severe motion sickness at some time	6-12%	6-13%	8-17%	4-8%	4-9%	4-10%

The data in Table 7 indicate that 6-10% of American adults riding in fully self-driving vehicles would be expected to often, usually, or always experience some level of motion sickness. In comparison, the highest expected percentage range is for Indians (8%-14%). Analogously, 6%-12% of American adults riding in fully self-driving vehicles would be expected to experience moderate or severe motion sickness at some time. Again, the highest expected percentage range is for Indians (8%-17%). (The differences between the nationalities are due to the differences in the expected involvement in activities that individuals would be doing while riding in fully self-driving vehicles [see Table 5].)

Minimizing motion sickness in self-driving vehicles

Vehicle design

In Table 1, we highlighted the three main factors contributing to motion sickness: conflict between vestibular and visual input, inability to anticipate the direction of motion, and lack of control over the direction of motion. By switching from driver to passenger*,* by definition, one gives up control over the direction of motion, and there are no remedies for this. The other two factors—the degree of conflict between vestibular and visual inputs, and the ability to anticipate the direction of motion—could be improved for passengers in self-driving vehicles. As pointed out in Table 1, these two factors are influenced by the extent of the visual field, the direction of gaze, and posture. In turn (1) the extent of the visual field can be maximized by having large, transparent windows (Diels, 2014), (2) the direction of the gaze can be optimized by having displays (e.g., for video, or work) oriented in such a way that the gaze is focused nearly straight ahead, or by having transparent (head-up) displays (Diels, 2014), and (3) posture can by optimized by not having swivel seats (Diels, 2014), by restricting head motion (Kato and Kitazaki, 2006), or by having fully reclining seats that would allow being in a supine position—laying down flat and facing up (Benson, 2002).

Additionally, recent research provides some support for two novel strategies for reducing the visual-vestibular conflict while watching videos. One approach imposes visual stimuli on or around the video screen to mimic the perceived motion and forces of the moving vehicle (Morimoto, Isu, Okumura, Araki, Kawai, and Masui, 2008). The other method involves controlling the position of displayed images in synchronization with vehicle motions and passenger head motions produced by vehicle acceleration/deceleration, thus providing video that appears to be stabilized in relation to the movement of the vehicle (Kato and Kitazaki, 2008).

Medications

Antiemetic medications (those designed to lessen or eliminate nausea and vomiting) have been developed to specifically address the symptoms associated with motion sickness. However, the effectiveness of these drugs varies, and there are several disadvantages in using this method for the treatment of motion sickness, such as undesirable side effects, the required administration of the drug well before exposure, and the required repeat dosing for prolonged exposure (Benson, 2002; Golding and Gresty, 2005; Reason and Brand, 1975).

Behavioral countermeasures

For those able to sleep in moving vehicles, sleeping reduces the frequency and severity of motion sickness, as does being awake with the eyes closed (Benson, 2002).

Important considerations

The present calculations provide only first-order approximations of what to expect in terms of the frequency and severity of motion sickness in self-driving vehicles because of the following considerations.

Self-driving vs. conventional vehicles

The calculations in this report were based on the assumptions that the cabin of self-driving vehicles would be similar to that of conventional vehicles, as would be the lateral and longitudinal acceleration profiles. To the extent that smaller, opaque, or reduced-visibility windows would be employed in self-driving vehicles, the frequency and severity of motion sickness would increase. Conversely, if self-driving vehicles would provide a smoother ride than conventional vehicles, the frequency and severity of motion sickness would decrease.

Effects of activities on motion sickness

The present calculations assumed no negative effect on motion sickness of either watching the road (despite the loss of control over the direction of the movement) or talking on the phone (despite not always being accompanied by watching the road). These are conservative assumptions, suggesting that the actual frequency and severity of motion sickness in self-driving vehicles might be greater than calculated in this report.

Another important assumption was that the effects of reading and watching video on motion sickness provide the higher and lower bounds for the effects of all other alternative activities that have negative effects on motion sickness (texting, working, and playing games). Future research related to this assumption would be useful.

Nature and frequency of alternative activities

The frequencies of how often persons would be involved in alternative activities while riding in self-driving vehicles in different countries were based on a recent survey that included activities currently available. To the extent that not only the frequencies of alternative activities but also their nature might be different when self-driving vehicles would become available in the future, the distributions of actual activities would need to be taken into account.

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