Title:

An international survey on the incidence and modulating factors of carsickness

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Abstract:

About two in three people have experienced carsickness at some point in their life (Reason & Brand, 1975). Little is known about current numbers of sufferers, cultural differences, or which modulating factors are being perceived as most relevant. Therefore, given a global increase of interest in carsickness driven by the development of automated vehicles, this survey intended to assess the status quo of carsickness in different parts of the world. We conducted an online survey with N = 4,479 participants in Brazil, China, Germany, UK and USA. 46% of participants indicated they had experienced some degree of carsickness in the past five years as a passenger in a car. When including childhood experiences, this rate increased to 59%, comparable to the 1975 findings by Reason and Brand. The highest and lowest incidence of carsickness was reported in China and Germany, respectively. In all countries, men and older participants reported a lower incidence of carsickness as compared to females and younger participants. The main modulating factors were found to be driving dynamics, visual activities, and low air quality. This study showed that carsickness still affects about 2/3 of passengers and discusses how its occurrence relates to in-transit activities and other modes of transport. The research provides a sound basis to further study how carsickness develops and to investigate countermeasures to potentially reduce it.

Keywords:

Motion Sickness; Carsickness; Passenger Comfort; Cultural Differences; International Survey

1 Introduction

1.1 Motion Sickness

Exposure to motion can lead to motion sickness, for instance as a result of being a car passenger on a winding road. This state of discomfort has been theorized to result from the discrepancy between anticipated and sensed motion (Reason & Brand, 1975; Oman, 1990; Bles, Bos, de Graaf, Groen & Wertheim, 1998), and occurs predominantly with low-frequency motion (O'Hanlon & McCauley, 1974). Although large inter-individual differences in terms of susceptibility have been observed (Reason & Brand, 1975 Bos, MacKinnon & Patterson, 2005), once it occurs, motion sickness initially manifests itself as a subset of symptoms such as (cold) sweating, dizziness, pallor, salivation, and apathy (Money, 1970). If the exposure to motion continues, these symptoms may be followed by nausea, culminating in retching and finally vomiting.

Though several theories have been proposed explaining motion sickness (see Previc, 2018, for a recent review), the organs of balance in our inner ears seem to play a key role in relation to motion sickness. Already at the end of the 19th century it was observed that totally deaf people were insensitive to motion sickness (Irwin, 1881; James, 1882). Interestingly these so called ‚labyrinthine defective' patients have also been shown not to suffer from sickness induced by visual motion while being physically stationary (Cheung, Howard, Nedzelski & Landolt, 1989; Cheung, Howard & Money, 1991; Johnson, Sunahara & Landolt, 1999). Blind people, on the other hand, do suffer from motion sickness (Graybiel, 1970), as do sighted people with eyes closed (Bos, MacKinnon & Patterson, 2005). These observations all point to the basic issue with motion sickness, i.e. motion and gravity as sensed by the organs of balance. For that reason, we consider all other factors that may affect motion sickness as modulating factors, such as vision or air quality.

To assess the incidence of real-world motion sickness for different transport modes, Reason and Brand (1975) and Turner and Griffin (1999b) conducted large scale surveys which, to date, still provide the most recent and comprehensive estimates available. However, these studies also suffered from a number of shortcomings. Firstly, the participant samples consisted of groups of undergraduates, male naval personnel, and young coach passengers, and may therefore not be representative of the wider population. Secondly, the studies were conducted in the UK and US and hence do not allow for international comparisons. Additionally, these studies did not take a minimal level of exposure into account. Also, given the observed differences in sickness estimates between the studies and their dated nature, there are several reasons to justify an update on the population estimate of the incidence of carsickness across various countries relative to other transportation modes.

While it is known that there are profound differences between various modes of transport, including motion frequency components, the travellers' visual scene, and typical durations of travel (e.g. Persson, 2008) – which further complicate the matter – these are beyond the scope of this paper. We focus here instead on a descriptive update of carsickness incidence in relation to the motion sickness incidences in other modes of transport.

1.2 Carsickness

According to Reason and Brand (1975), about two thirds of undergraduate car passengers have suffered from sickness at some moment throughout their lifetime, with about half of them also reaching the limit of vomiting. Similarly, a field survey of coach passengers by Turner and Griffin (1999b) indicated that 37% of these passengers reported having previously suffered with motion sickness in cars, with the percentage dropping to 23% for coaches. The reason for the lower carsickness incidence rate in this study compared to that of Reason and Brand is difficult to determine based on the information given.

Carsickness is a form of motion sickness that occurs in road vehicles. It is principally caused by the vehicle's motion with more dynamic driving styles, i.e. higher accelerations, leading to elevated sickness levels (Turner & Griffin, 1999a). In addition, there are several other factors affecting the occurrence of carsickness. The most important one concerns the observation that drivers suffer considerably less from carsickness than passengers do, irrespective of being exposed to the same motion. This can largely be explained by the fact that drivers can control and therefore better anticipate the motion of the vehicle as compared to passengers, reducing discrepancies between expected and sensed motion (Rolnick & Lubow, 1991).

Another important factor in understanding carsickness is vision. Visual-vestibular discrepancies, such as when reading a book or watching a computer screen in a moving vehicle, can exacerbate carsickness considerably (Bles, Bos, de Graaf, Groen & Wertheim, 1998; Bos, Bles & Groen, 2008; Kuiper, Bos & Diels, 2018; Diels, Bos, Hottelart & Reilhac, 2016). Conversely, ample out-the-window vision can reduce carsickness, especially when looking at the road ahead. This beneficial effect is likely to be as a result of being able to anticipate upcoming motion (Probst, Krafczyk, Büchele & Brandt, 1982; Griffin & Newman, 2004; Turner & Griffin, 1999b; Perrin, Lion, Bosser, Gauchard & Meistelman, 2013). The possibility to anticipate upcoming motion is reduced by a backward seated orientation, which has been found to increase sickness (Turner & Griffin, 1999b; Salter, Diels, Herriotts, Kanarachos & Thake, 2019). Being exposed to critical motion with closed eyes has been found to be less provocative, possibly a par with out-the-window vision (Griffin & Newman, 2004; Bos et al., 2005).

Women have been found to be considerably more susceptible to motion sickness than men (see e.g. Klosterhalfen, Kellermann, Pan, Stockhorst, Hall & Enck, 2005; Bos et al., 2007; Paillard, Quarck, Paolino, Denise, Paolino, Golding et al., 2013). This, however, is typically observed when using self-ratings, and could be assumed to be a gender (i.e., cultural), rather than a sexual (i.e., physiological) difference. When focusing on vomiting, for example, the difference is generally not observed (Cheung & Hofer, 2002). Susceptibility to motion sickness has been found to increase with age – peaking in youth and decreasing thereafter (Bos, Damala, Lewis, Ganguly & Turan, 2007). Susceptibility to motion sickness in general is found to also have a genetic component (Hromatka, Tung, Kiefer, Do, Hinds & Eriksson, 2015; Bakwin, 1971). This is reflected in the findings that Asian individuals are more susceptible to motion sickness compared to Caucasians (Stern, Hu, Anderson, Leibowitz & Koch, 1996; Klosterhalfen et al., 2005). To our knowledge, the vast majority of literature on carsickness does not take ethnicity into account. This might lead to an underestimation of the occurrence of carsickness when translating general observations to Asian populations in particular or an overestimation vice versa.

Lastly, there are several other factors affecting motion sickness, which we will only mention briefly here. Lying on one's back, for example, reduces sickness (Vogel, Kohlhaas & von Baumgarten, 1982; Golding, Markey & Stott, 1995). The effect of odours is still somewhat controversial, however, unpleasant odors, particularly those associated with the vehicle in question, could have a negative effect (Paillard, Jacquot & Millot, 2011; Perrin, Lion, Bosser, Gauchard & Meistelman, 2013 versus Paillard, Lamôré, Etard, Millot, Jacquot, Denise et al., 2014). Airflow, on the other hand, has been shown to significantly reduce motion sickness (D'Amour, Bos & Keshavarz, 2017). Other studies have revealed, the mental expectation of becoming sick might increase its occurrence as a self-fulfilling prophecy (Eden & Zuk, 1995), while mental distraction has been shown to decrease sickness severity (Bos, 2015). The latter may also explain the beneficial effects of pleasant music (Keshavarz & Hecht, 2014).

To our knowledge, no systematic studies exist on the typical time course of carsickness under realistic conditions. Basic motion sickness studies showed that under provocative conditions the onset time of signs and symptoms can vary considerably but is normally in the order of ten to twenty minutes (O'Hanlon and McCauley, 1974; Griffin & Newman, 2004).

1.3 Aim of Study

Given the dated literature on the incidence of carsickness, coupled with the observation that globally cars increasingly account for the vast majority of passenger kilometres (see, e.g., Eurostat, 2018), an update of the incidence of carsickness would be valuable. In addition, the available data sets are typically restricted to one country, thereby omitting the differences that could be expected between different countries based on differences in genetics, transportation behaviour and infrastructure. Another development that makes survey data on carsickness more relevant, is the expected introduction of automated vehicles over the coming decades (Litman, 2014). This will increase the kilometres travelled by passengers, in particular by those engaging in non-driving related tasks, which can be expected to increase the overall occurrence of carsickness (Diels & Bos, 2016). Therefore, the aim of this study is to conduct a large-scale survey to assess the incidence of carsickness across several countries, including the modulating factors of carsickness and how these relate to other modes of transport.

2 Materials and Methods

To collect data from a large number of respondents in several countries with an extensive use of cars and public transportation in a consistent way, we elected to conduct an online survey. We only included participants that regularly used public transport and/or privately-owned cars, since these are the populations potentially at risk of carsickness. Based on these conditions, as well as the goal to include countries from different continents, we selected Brazil, the People's Republic of China, Germany, the United Kingdom, and the United States of America for our survey.

2.1 Questionnaire

A questionnaire was developed in the English language, programmed, tested and optimized for usability and language with a sample of experts including native English speakers. Subsequently, professional translators translated the questionnaire into Mandarin Chinese, German and Portuguese. Bilingual speakers finally checked these versions for consistency with the original English draft.

In accordance with the basic items discussed in the introduction, the survey consisted of the following sections:

1) Welcome and assurance of anonymity; 2) Demographics including gender, age, and vehicle ownership; 3) Seating choices in a hypothetical transportation situation; 4) Transportation behaviour, frequency of motion sickness in different transport modes; and 5) Modulating factors and countermeasures.

The wording of each item of relevance for this part of the study is reported in the results section. The objective of each of the questionnaire sections described above is summarized in the appendix.

2.2 Participants, Sampling Procedure and Data Collection

In total, N = 4,479 complete cases were obtained and subjected to statistical analysis.

A market research agency recruited the participants using online panels in which specific demographics could be selected. Informed consent was obtained from each participant and they were reassured that all responses would be kept strictly confidential and only analysed in anonymous form. This research complied with the American Psychological Association Code of Ethics and an explicit approval was obtained by TNO[1] Institutional Review Board

Respondents were selected to ensure the sample 1) consisted of those over 18 years of age, 2) was representative of the gender and age distribution of car owners in that country, and 3) consisted of 50% for whom a car was the primary mode of transport and 50% for whom public transportation was the primary mode.

Based on these criteria, a total of 16,315 individuals were invited to participate. After survey completion, participants received credits that could be collected and exchanged for vouchers of commercial online platforms.

Data collection took place from June 31st to August 18th 2017. 45.5% of the invitees started the survey, and 73% of those who started completed it. Median duration to complete the total survey was 13 minutes. The market research agency delivered 4,500 quality-screened cases, of which 21 had to be excluded by the researchers due to obvious inconsistencies.

[1] Netherlands Organisation for Applied Scientific Research, to which authors Kuiper and Bos were affiliated.

2.3 Basic Sample Properties: Country, Gender and Age

Figure 1 shows the gender and age distribution for each of the countries assessed. Because the sample was primarily recruited to resemble the car owner population of each country, there were clear differences between countries with regards to the age distributions.

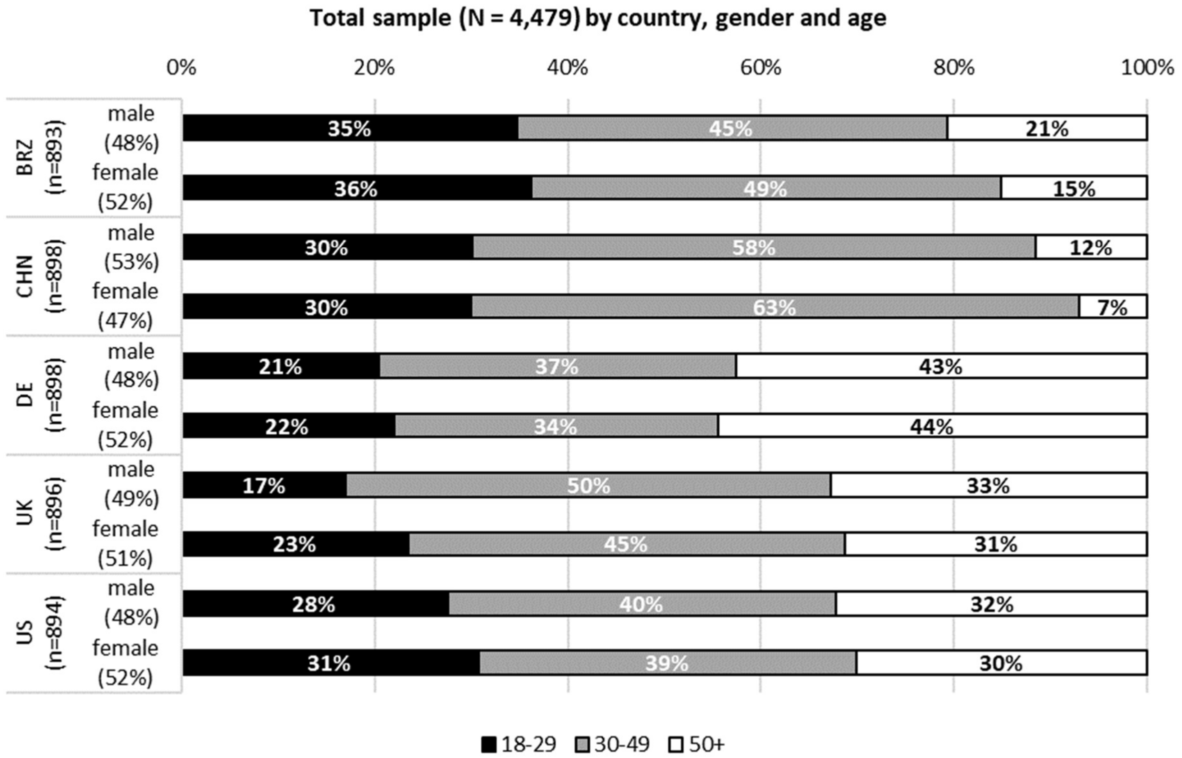

Figure 1. Final sample composition (N = 4,479) by country, gender and age.

2.4 Definition and Incidence of Motion Sickness

In order to ensure the same understanding of motion sickness in each country, a definition was provided at the start of the respective section of the questionnaire: "*Motion sickness is a condition of feeling unwell which can occur when traveling in anything from ships (seasickness), cars (carsickness), to rollercoasters. Symptoms differ between people but often include fatigue, dizziness, sweating, nausea and eventually vomiting*."

Motion sickness incidence rates for each mode of transport were then based on the item *"At any moment in the last five years, have you experienced any symptoms of motion sickness"*. A person having experienced motion sickness was then defined as anyone who did not answer *"No, never"*.

2.5 Statistical Analysis

Wherever applicable, 95% confidence intervals will be displayed estimating population proportions.

Effects of gender, age, and country are reported by means of a binary logistic regression, testing the association between those three factors and the likelihood of reporting carsickness. The effect of different modulating factors on the onset time of carsickness, were tested by means of a one-way between-subjects ANOVA supplemented by a post-hoc Tukey pairwise comparisons test. For all statistical tests, the alpha levels were set to .05.

3 Results

3.1 Transportation Behaviour

Overall, there was sufficient general mobility experience in the sample, as 92.6% used any form of mobility “a few times a week or more”, 98.9% “a few times a month or more” and 99.8% “a few times a year or more”. Figure 2 displays the frequency of use for the different transport modes assessed. It can be seen that the predominant use of either public transport or of a car/truck/van as a recruitment criterion was successful in enabling a sufficient variance in use of different transport modes. All three vehicle types were named in the English surveys, since especially in the United States trucks and vans are seen as separate vehicle types than cars. For ease of reading, in the following we will only refer to “cars” but also include vans and trucks.

To ensure a sufficient level of exposure, for all incidence data, the sample was limited to those that actually used the respective transport mode at least “a few times a year” reducing it to 4,268 cases for car users in any position in the vehicle.

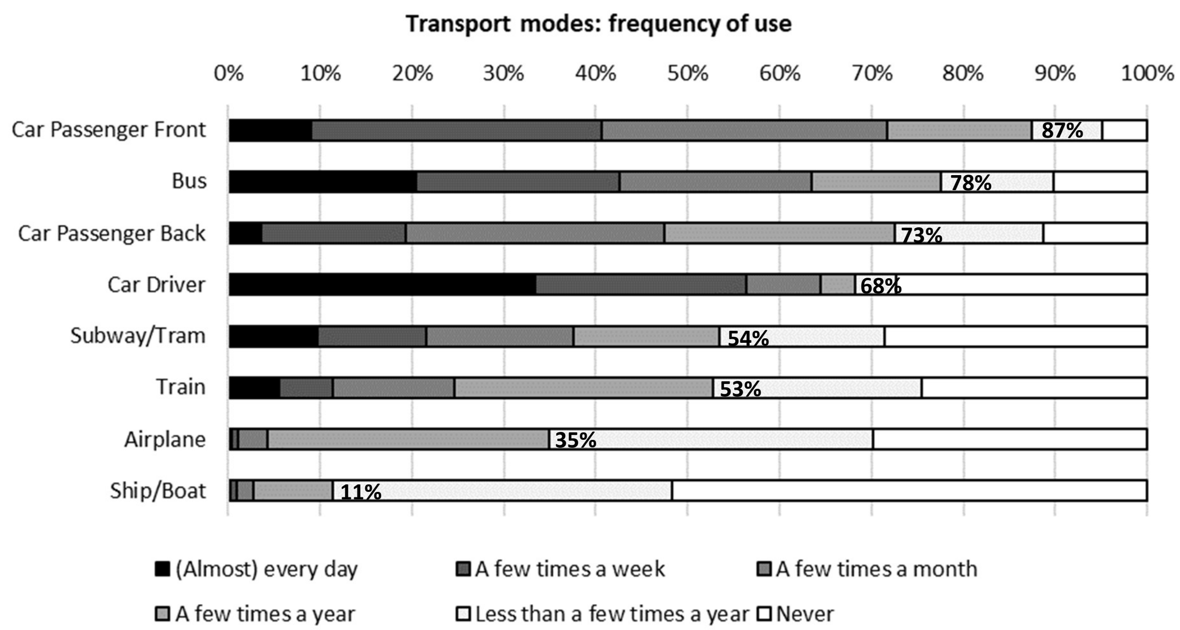

Figure 2. Frequency of use for each transport mode. Percentages indicate the share of participants that use a certain mode of transport at least “a few times a year”. [Item wording: *“Below is a list of modes of transportation. During the past five years, how often have you used each of the following?”*]

3.2 Incidence, Frequency and Severity of Motion Sickness

Of all car users (n = 4,268), 45.6% (95%-CI: 44.1% - 47.1%) reported having experienced carsickness at some point in the last five years. When limited to those who had travelled as a *passenger* in a car at least a few times a year (n = 4,084), this rate increased to 46.3% (95%-CI: 44.8% - 47.9%). The higher rate for the latter can be explained by the fact that car occupants that only travelled in a car as a driver, who tend to be less susceptible to carsickness as discussed earlier, were excluded in this analysis.

Figure 3 indicates that for car passengers the position on the back seat results in the highest incidence (46.4%; CI: 44.7% - 48.1%), which – based on the 95% CIs – is significantly different from the incidence in the front seat position (36.7%; CI: 34.2% - 37.2%) as well as in the car driver position (17.2%; CI: 15.9% - 18.6%). Of all transport modes, motion sickness incidence was highest in Boat/Ship travel (62.1%; CI: 58.0% - 66.4%) and significantly different from all other modes of transport.

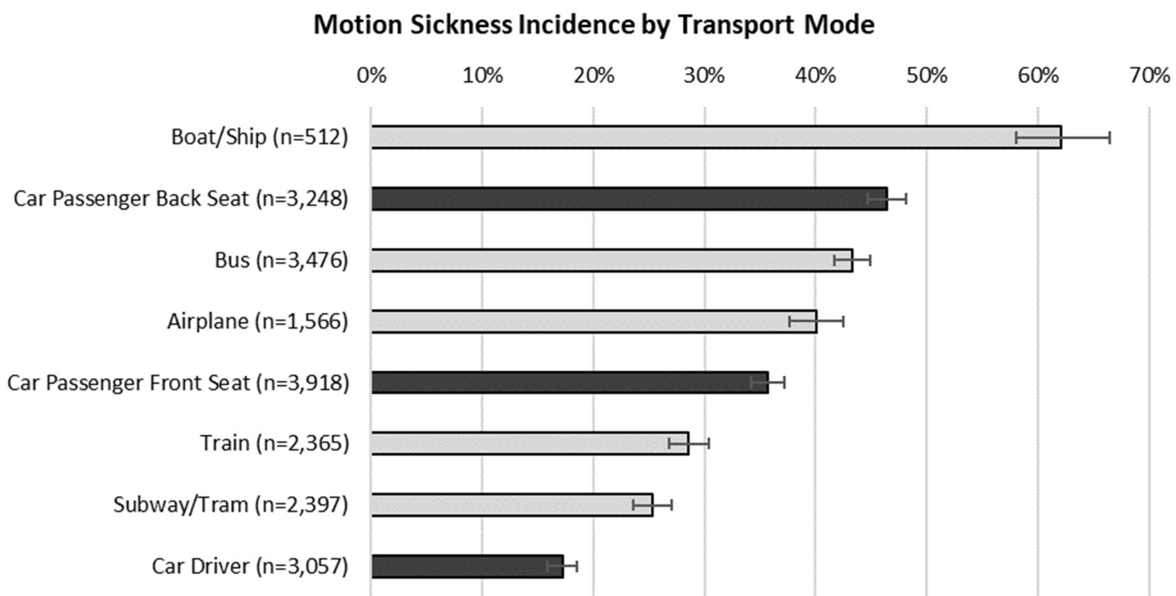

Figure 3. Motion sickness incidence in the last five years by users of each mode of transport sorted by incidence. The dark grey bars indicate the three different roles while traveling in a car. Error bars indicate the 95%-confidence interval for proportions. [Item wording: *"At any moment in the last five years, have you experienced any symptoms of motion sickness"*]

Figure 4 shows the frequency of carsickness broken down by answer categories. While the proportions in all other categories are well proportional to the overall incidence rate at each position in the vehicle, there is a surprisingly high percentage of car drivers who confirmed experiencing carsickness "*(almost) always*" (3.9%).

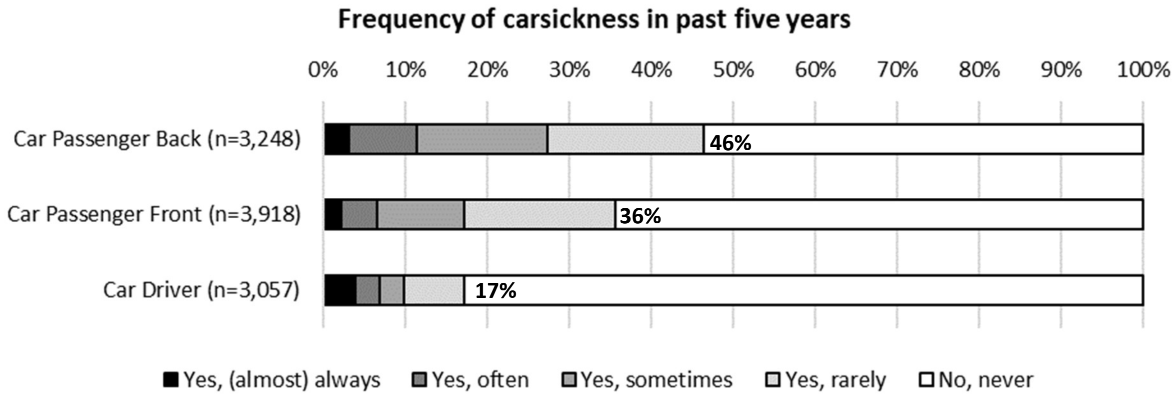

Figure 4. Frequency of carsickness for car users in past five years. Percentages added indicate the share of participants that experienced any carsickness.

All car passengers that had reported carsickness in the previous five years (n = 1,892) were given the choice between the statements - "*I only experience motion sickness when I don't look outside the front window for some time and engage in other activities*" and *"Even if I look outside the entire time, it may happen that I become motion sick*" 45.5% (CI: 43.2% - 47.7%) indicated that not looking outside is a necessary precursor for carsickness to occur. 54.5% (CI: 52.3% - 56.8%) indicated that carsickness may also occur when constantly looking outside the moving vehicle.

Figure 5 shows the severity of the worst incidence of carsickness in the past five years. A chi-square test revealed higher severity levels in the group that experiences carsickness even when looking outside ($\chi^2(4) = 71.43$; $p < .001$).

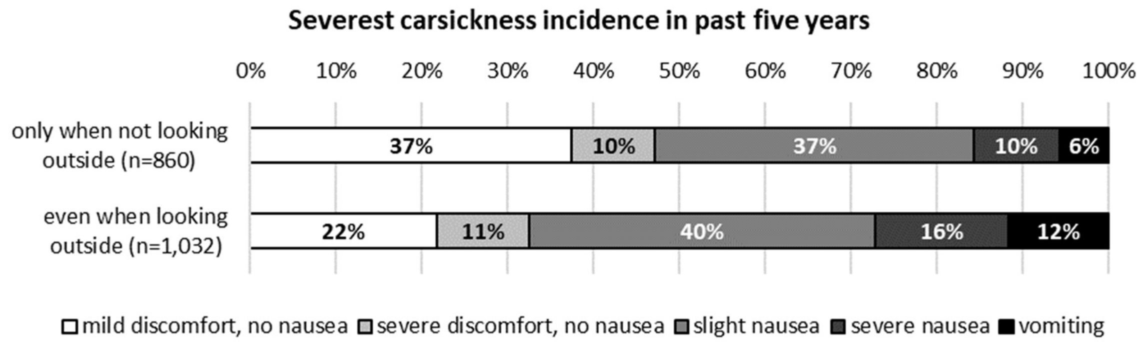

Figure 5. Severest carsickness incidence for car users in past five years by carsickness type. [*Item wording: "Now please think about the worst incidence of motion sickness that you experienced over the past five years when riding in a car/truck/van. On a scale from 1 (mild discomfort) to 5 (vomiting), how severe were the symptoms you experienced?"*]

In order to explore carsickness along the entire lifespan, those participants that reported no carsickness in the previous five years were asked "*Did you experience any symptoms of motion* *sickness in a car at any other moment in your lifetime - including your childhood*?" Based on the overall sample of car users, an additional 13.1% (CI: 10.3% - 16.0%; BRZ: 17.4%, CHN: 7.8%, DE: 13.0%, UK: 16.1%, US: 11.0%) indicated that this was the case, resulting in an overall lifespan incidence of 59.4% (CI: 57.5% - 61.4%; BRZ: 62.3%, CHN: 70.4%, DE: 48.5%, UK: 59.5%, US: 55.6%).

3.3 Influence of Country, Gender and Age

Figure 6 shows carsickness incidence by country, gender and age. It is noticeable that there are very large differences between the individual cells reported. For instance, 81.7% of the Chinese females below the age of 30 reported carsickness, while only 11.5% of the Brazilian males 50 years and older did so. Yet, across countries, age and gender effects are consistently observed. Looking at the incidences reported within each country, the highest proportion by far was reported in China (61.7%), followed by Brazil (44.5%), US (44.2%), UK (42.8%), with the lowest proportion observed in Germany (34.3%).

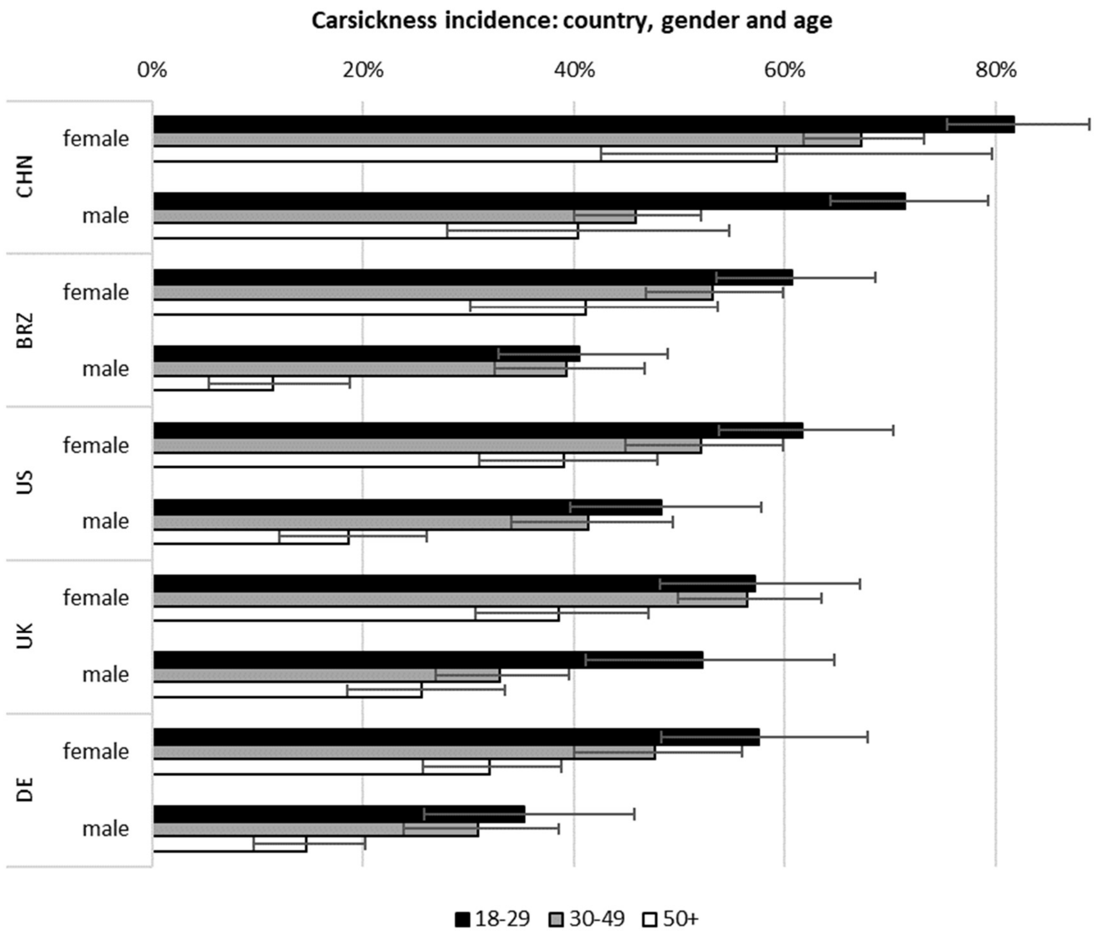

Figure 6. Carsickness incidence for car users by country, gender, and age. Error bars indicate the 95%-confidence intervals.

Since the descriptive analysis showed no indications of any sizeable interactions for the factors: country, gender, or age group, only main effects were modelled in the binary logistic regression. Results indicated a significant association between age, gender, country, and the likelihood of participants reporting carsickness ($\chi^2(7) = 427.62$, $p < .001$). The individual predictors were examined further and indicated that country ($\chi^2(7) = 97.74$, $p < .001$), gender ($\chi^2(7) = 135.46$, $p < .001$) and age group ($\chi^2(7) = 149.40$, $p < .001$) were all significant predictors in the model. The total adjusted R^2 of the model was 7.15%.

Table 1 summarizes the odds ratios for the levels of each predictor. For example, individuals belonging to the age group 18-29 have a more than three times higher chance of experiencing carsickness than those individuals belonging to the age group 50 and older.

Table 1

Odds ratios for binary logistic regression for carsickness likelihood. For each predictor the group with the lowest likelihood was chosen as the reference. Given that all lower 95% CIs are >1.00, all predictor levels differ significantly from the reference level.

Predictor	Level	Odds Ratio	Lower 95% CI	Upper 95% CI
Country	*Germany (Ref)*	*1.00*	-	-
	Brazil	1.25	1.02	1.53
	UK	1.37	1.12	1.68
	US	1.37	1.12	1.69
	China	2.62	2.13	3.23
Gender	*Male (Ref)*	*1.00*	-	-
	Female	2.12	1.86	2.41
Age Group	*50+ (Ref)*	*1.00*	-	-
	30-49	1.95	1.65	2.30
	18-29	3.02	2.53	3.63

3.4 Subjectively Reported Modulating Factors

For this analysis only carsick car users (n = 1,892) were included. For nineteen travel conditions, which were derived from the existing literature as well as a pilot questionnaire, participants indicated how likely they would experience carsickness under these conditions. Figure 7 shows the percentage of participants that indicated "*likely*" or "*very likely*". For nine potential modulating factors, significantly more than half of the participants indicated that they would at least be *likely* to experience carsickness under these conditions.

The factors that were reported to lead to most carsickness were those that can cause repeated lateral and longitudinal accelerations at considerable magnitude (many turns [71.8%], curvy roads [70.5%], stop-and-go traffic [56.9%]), aspects that influence subjective air quality (cigarette or exhaust smell) [71.2%], warm air [57.9%]) and different visual activities (reading [67.1%], writing [59.4%], using a device [61.7%], watching video [58.0%]).

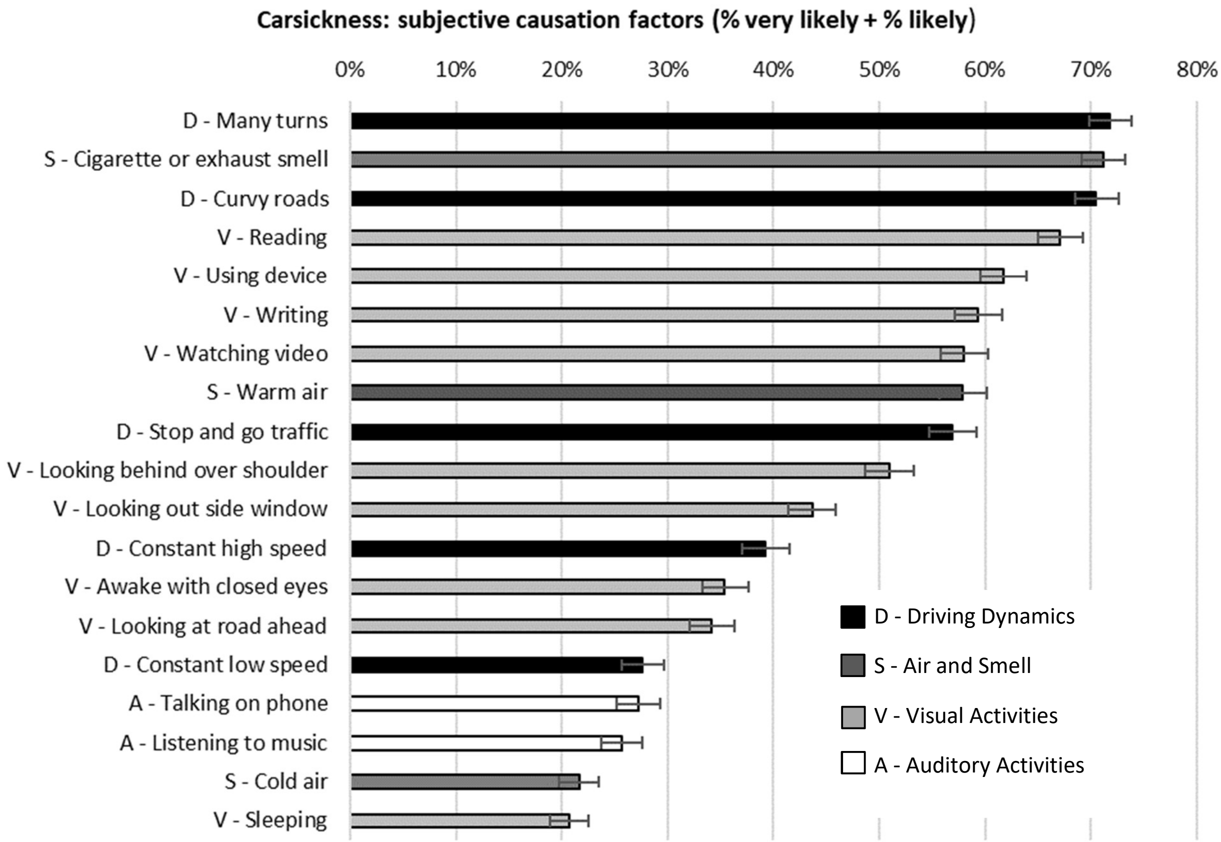

Figure 7. Percentage of participants indicating that they are *likely* or *very likely* to experience carsickness under each of the indicated conditions. Differences in bar colours indicate the four different modalities. Error bars indicate 95% confidence intervals for proportions. [Item wording: "*While a passenger in a car, how likely are you to experience motion sickness in the following situations?*"]

3.5 Symptom Onset Time per Modulating Factor

Participants were asked to estimate the time elapsed until first symptoms would appear for the modulating factor that was rated as most potent by them. In order to ensure a sufficient sample size per factor, it was decided to pool the data into three modalities based on the three highest rated modulating factors for each category. This resulted in pooling the data into *visual activities* (reading [n = 148], writing [n = 123], using a device [n = 96]), *driving dynamics* (many turns [n = 122], curvy roads [n = 105], stop and go traffic [n = 86]) and *air and smell* (cigarette or exhaust smell [n = 181], warm air [n = 63]). One extreme outlier who reported 10 hours of exposure until symptoms appeared was excluded.

The empirical cumulative distribution functions in Figure 8 illustrate the range of symptom onset times that were reported by the participants. Table 2 depicts the mean and median values.

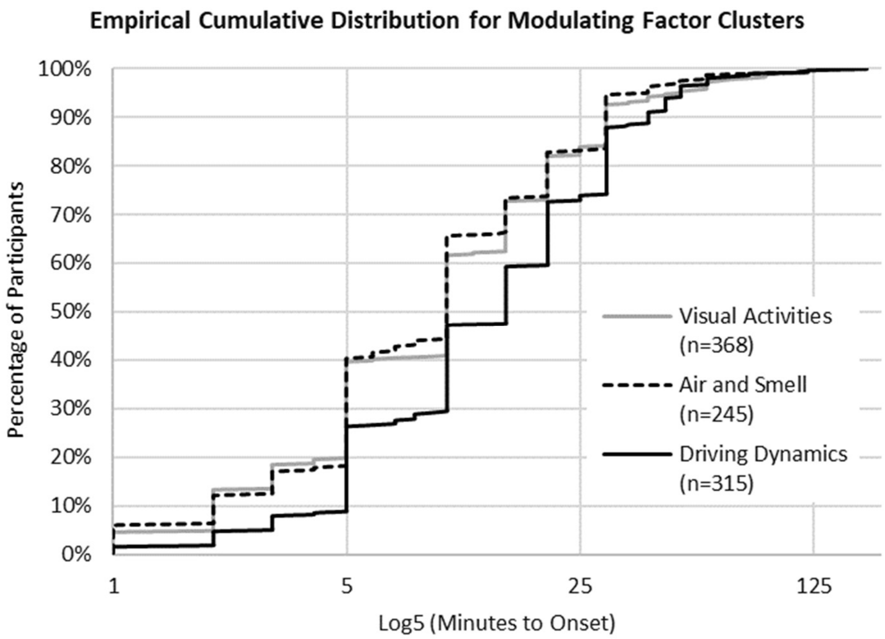

Figure 8. Empirical cumulative distribution for modulating factor clusters visual activities (reading; writing; using a device), air and smell (cigarette or exhaust smell; warm air) and driving dynamics (many turns; curvy roads; stop and go traffic). [Item wording: "*When being exposed to a situation (e.g. [situation x]) where you may end up become motion sick as a passenger in a car, how many minutes before you feel the first symptoms of motion sickness? Please make your best guess:*"]

Table 2

Descriptive statistics and confidence intervals for carsickness onset time in minutes for each modulating factor cluster

Factor	n	Median	Mean	Lower 95% CI	Upper 95% CI
Air and Smell	245	10	13.84	11.59	16.09
Visual Activities	368	10	15.06	13.23	16.90
Driving Dynamics	315	15	18.90	16.92	20.89

A one-way ANOVA revealed a significant effect of the three-level factor *type of modulating factor* (F(2, 925) = 6.39; *p* = .002) indicating the presence of a difference between the three factor levels. A post-hoc Tukey pairwise comparisons test for differences in mean symptom onset times between the individual factor levels revealed that both v*isual activities* (T(681) = 2.79; *p* = .015) as well as *air and smell* (T(558) = 3.31; *p* = .003) showed significantly lower subjective onset times than *driving dynamics*. The pairwise comparison between *visual activities* and *air and smell* did not reveal any significant difference in mean onset times (T(611) = -.83; *p* = .687).

4 Discussion

4.1 Carsickness Incidence

We found carsickness was experienced by 46% of car occupants in the last five years, increasing to 59% when considering their entire lifespan. These findings are similar to those reported by Reason and Brand (1975), who found two-thirds of participants reporting some illness at any point in their lives. Carsickness therefore remains an issue affecting a similar proportion of car users as it did more than 40 years ago.

This is the first study to explicitly compare carsickness incidence to motion sickness incidence in other transport modes. It is notable that in our study the incidence of motion sickness on the backseat of a car and in a bus was found to be similar (48% vs. 45%). In contrast, Turner and Griffin (1999b) observed a considerable difference between incidence levels between car (37%) and bus (23%). The effects on reported sickness related to seating position and activity are in line with the hypothesis that the availability of out-the-window visual information as well as being in control of the vehicle (as a driver) reduce the likelihood of carsickness. Finally, it is worth mentioning that both rail-bound modes of transport (train and tram) seem to cause significantly less motion sickness as compared to the other modes of transport considered. A likely explanation is a lower magnitude of lateral, longitudinal as well as vertical accelerations (Förstberg, 2000; Persson, 2008).

Above the age of 18, we found carsickness to decrease monotonically with increasing age, which is in line with other studies on motion sickness (Bos et al., 2007; Paillard et al., 2013). Also in line with the literature (e.g. Klosterhalfen et al., 2005; Bos et al., 2007; Paillard et al, 2013), we found women reporting higher incidences of carsickness by a factor of 2.12. Given the unclear evidence whether this is a physiological effect or a cultural effect as a result of self-reporting, we can only conclude that, subjectively, carsickness appears to be more of an issue in the female population. This might also make females more likely to show interest in countermeasures and benefit from these.

Respondents from China reported the highest levels of carsickness, those from Germany the lowest (e.g. 58% vs. 40% in age group 30 to 49). Previous research has suggested a genetic origin for the frequently observed higher susceptibility in the Asian population (Klosterhalfen et al., 2005). Whether the observed difference in this study can be attributed to genetic differences can however not be asserted since we assessed residency and not ethnicity. At the same time, genetics may have played at least some role in particular given the relatively low number of immigrants in China (Heberer, 2017). This matter is further complicated by the fact that other factors such as road design, traffic-density as well as the prevalence and type of passenger activities (e.g. smartphone use) may also differ between countries.

Interestingly, 3.9% of car drivers indicated “almost always” experiencing carsickness. This unexpected finding proved not to be the result of spurious data (e.g. inconsistent reports) and suggests a small portion of drivers consistently experience mild carsickness. However, given the limited sample size, these findings need to be interpreted with caution.

4.2 Modulating Factors

The overall picture of the modulating factors was aligned with the existing literature. Namely, lateral and longitudinal accelerations, visual activities, and unpleasant odours are reported to increase carsickness, while low dynamics, non-visual activities, looking outside, and sleeping are associated with less carsickness. Apart from validating often heard anecdotal reports on these issues, these findings also validate the survey approach used here, and proves that people have considerable awareness of relevant modulating factors.

One finding of particular interest is that looking at moving images (video) is rated as significantly less provoking than looking at stationary content (reading). This is in line with some recent studies (Isu, Hasegawa, Takeuchi &Morimoto, 2014; Schoettle & Sivak, 2009), but not with the assumption that adding potentially conflicting motion could lead to even more (visually induced) sickness (Keshavarz et al., 2015). Given the limitation that the participants' judgments are likely to be based on less experience with watching videos than reading and the assumption that the actual content and ergonomic position of the video vs. reading content is highly variable, further experimental studies are needed to shed more light on these conflicting claims.

Concerning the reported exposure times until onset of first symptoms, the mean durations reported here (14 to 19 minutes depending on modality) are comparable to other research that has shown significant levels of carsickness after ten minutes of exposure to provoking conditions (Griffin & Newman, 2004; Kuiper et al., 2018). Unsurprisingly for a survey study, participants report a very large range of durations.

4.3 Methodological Limitations

One point of criticism on the use of self-report surveys concerns the effect of poor memory. Despite evidence that in questionnaires individuals can make good estimations of events in the past (Sobell, Block, Koslowe, Tobin & Andres, 1989), an under or overestimation cannot be fully ruled out.

The use of online panels has advantages and disadvantages (Evans & Mathur, 2005). One advantage is that they can have a higher attentional involvement than college student populations (Hauser & Schwarz, 2016). On the other hand, online surveys may attract a biased sample due to not reaching individuals without internet access. However, in recent years, access to internet is widespread in the countries we selected and online surveys can be of equal quality to conventional studies (Hauser & Schwarz, 2016). Traditional pen-and-paper surveys have their own selection biases, e.g. being limited to recruiting near the research institute. In general, by focusing on individuals using public transport or privately-owned cars, we attained a representative sample of the general population for which motion sickness is a potential issue and thus can actually give an accurate indication of their susceptibility.

Finally, we decided not to include detailed correlations between frequency of use and motion sickness incidence – although these could be of great interest. Given the rather coarse assessment of these variables and the multitude of additional confounding factors we consider it more appropriate to design dedicated field studies assessing carsickness on a trip by trip basis while also taking into account additional aspects of interest such as habituation.

5 Conclusions

With 46% of car occupants having experienced symptoms of carsickness in the past five years, and 59% having experienced carsickness during the course of their lives, sickness is still a common unpleasant side effect of traveling by car. Only ships or boats were found to be more provocative than cars. While busses were associated with similar motion sickness as cars, other modes of transport such as planes, trains, and trams were reportedly less problematic. The cultural (China > other), age (younger > older) and gender (females > males) effects should be taken into account when discussing the relevance of the problem – especially when inferring from specific samples to general conclusions. These effects might also be interesting for the targeted development of countermeasures.

This knowledge on the extent to which passengers of present-day vehicles experience carsickness, and how this is influenced by various non-driving tasks (such as display use) can be used to better understand the possible effect on occupant comfort in autonomous vehicles. While autonomous vehicles could lead to more carsickness due to more people traveling as passengers possibly engaged in visual non-driving related activities (Diels & Bos, 2016), knowledge on the current risk factors for carsickness could aid in designing vehicles and driving algorithms that minimize the occupants' carsickness. Moreover, the observation that in the past 40 years susceptibility to carsickness did not decrease significantly, refutes the assumption that adaptation will solve the problem by itself. In the coming decades, gaining control of carsickness might be an important enabler for acceptance of AVs and therefore for leveraging potential positive effects on traffic safety and environmental impacts.

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Appendix:

Definitions of Motion Sickness used in Survey:

English: Motion sickness is a condition of feeling unwell which can occur when traveling in anything from ships (seasickness), cars (carsickness), to rollercoasters. Symptoms differ between people but often include fatigue, dizziness, sweating, nausea and eventually vomiting.

German: Bei der Reisekrankheit handelt es sich um ein Gefühl des Unwohlseins, das beim Reisen mit verschiedensten Verkehrsmitteln von Schiffen (Seekrankheit) über Autos bis hin zu Achterbahnen auftreten kann. Die Symptome unterscheiden sich je nach Person. Oft gehören dazu Müdigkeit, Schwindel, Schwitzen und Übelkeit bis hin zum Erbrechen.

Portuguese: Enjoo é uma condição de se sentir mal, que pode ocorrer quando se viaja em qualquer coisa, desde navios, carros, até montanhas-russas. Os sintomas diferem entre as pessoas, mas geralmente incluem fadiga, tonturas, transpiração, náuseas e eventualmente vômitos.

Chinese: 晕动病是指在乘船（晕船）、乘车（晕车）以及坐过山车时感觉不适的状况。症状因人而异，但通常包括疲劳、头晕、出汗、恶心以及最终呕吐。

Objective of Overall Questionnaire Sections

1) *Welcome and assurance of anonymity*: Overall introduction of topic ("your experiences in transportation") and approximate duration of survey (15 minutes).

2) *Demographics including gender, age, and vehicle ownership*: Self report of primary mode of transport was assessed to allow for screening of 50/50 distribution of car users and public transport users. Vehicle ownership was used for internal exploratory analyses.

3) *Seating choices in a hypothetical transportation situation*: This section was designed as a choice task where the participants had to decide whether they would get into a ride sharing vehicle with a certain occupancy based on the number of open seats and the directionality of the seats available. Also explicit preference for different seating layouts was assessed.

4) *Transportation behaviour, frequency of motion sickness in different transport modes*: This section contained the items reported in sections 2.3, 3.1 and 3.2 of this paper. Motion sickness as a topic was not introduced until this part of the survey.

5) *Modulating factors and countermeasures*: This section contained the items reported in sections 3.3 and 3.4 of this paper. In addition, this part of the questionnaire was designed to find out what actions people take before they start a car ride or during the car ride in order to prevent or mitigate motion sickness and whether they have experienced these countermeasures to be helpful for them. Also, some items were included to assess experiences and preferences with seating directionalities in buses, trains/trams and taxis.