Visuospatial Training Does Not Reduce Motion Sickness Susceptibility

Michael Wiesing, Eckart Zimmermann, Eike A. Schmidt, Axel Buchner

UNIVERSITY of CALIFORNIA PRESS | Collabra: Psychology

Wiesing, M., Zimmermann, E., Schmidt, E. A., & Buchner, A. (2024). Visuospatial Training Does Not Reduce Motion Sickness Susceptibility. *Collabra: Psychology*, *10*(1). https://doi.org/10.1525/collabra.121390

Cognitive Psychology

Visuospatial Training Does Not Reduce Motion Sickness Susceptibility

Michael Wiesing[1], Eckart Zimmermann[1], Eike A. Schmidt[1], Axel Buchner[1][a]

[1] Department of Experimental Psychology, Heinrich Heine University Düsseldorf, Düsseldorf, Germany

Keywords: motion sickness susceptibility, motion sickness reduction, visuospatial skills

https://doi.org/10.1525/collabra.121390

Collabra: Psychology

Vol. 10, Issue 1, 2024

Smyth et al. (2021) reported the results of a driving study which they interpreted as suggesting that working on visuospatial problems is an effective method to reduce the susceptibility to motion sickness while they also mentioned that the reason as to why this should be the case is unknown. Here we present a conceptual replication of their study using a much larger sample size than that of the original study. A 30-minute simulated drive in a virtual environment was used to induce motion sickness. During the subsequent 14 days, participants in the visuospatial-training group, but not participants in the no-training group, worked on visuospatial problems for 15 minutes a day, as in the original study. Participants then returned to the laboratory for their second 30-minute simulated drive. Motion sickness severity was substantially reduced from the first to the second drive, but the visuospatial training did not significantly affect this reduction in motion sickness. We conclude that working on visuospatial problems does not reduce the susceptibility to motion sickness.

Autonomous vehicles on the road are expected to provide many benefits, an increased productivity of the drivers being one of them. Drivers who are released from engaging in actions associated with driving may engage in productive activities en route (Bagloee et al., 2016) such as reading and writing. In this case, however, motion sickness may become even more of a problem than it currently is due to the desynchronization of the visual, vestibular and somatosensory stimulation (Cha et al., 2021; Keshavarz & Golding, 2022). It thus seems desirable to search for methods of reducing people's susceptibility to motion sickness.

Such a method has been proposed by Smyth et al. (2021) and the data they report seem to suggest that their method is quite effective. In the critical 'Part 2' of their study, N = 15 participants were assigned to a visuospatial-training group and N = 7 participants were assigned to a no-training control group. All participants initially received a standardized driving experience designed to induce motion sickness (they were driven around for 30 minutes while sitting in the backseat of a car and reading text) which was assessed using the Fast Motion Sickness Scale (Keshavarz & Hecht, 2011), followed by a more extensive motion sickness assessment using the Simulator Sickness Questionnaire (Kennedy et al., 1993). After a period of 14 days, participants received a second, identical driving experience and subsequent motion sickness assessment, again using the Simulator Sickness Questionnaire. Smyth et al. (2021) reported that performing a fifteen-minute visuospatial training on each of the 14 days between the two driving experiences reduced motion sickness by 58.5 % from the first to the second driving experience in the visuospatial-training group. In contrast, motion sickness even increased descriptively by 4 % from the first to the second driving experience in the no-training control group. Smyth et al. (2021) further reported that the visuospatial-training group and the no-training control group differed significantly in how motion sickness changed from the first assessment to the second assessment. This difference in motion-sickness change between the visuospatial-training group and the no-training control group was associated with a sample effect size of f = 0.84. To put this into perspective, an effect of f = 0.40 is already classified as large in terms of the effect size conventions suggested by Cohen (1988). Given this, the sample effect size of the visuospatial training effect reported by Smyth et al. (2021) must be considered huge. If a simple visuospatial training would indeed prove to be so hugely effective at reducing motion sickness, then this would be very good news for people suffering from motion sickness and for manufacturers of future autonomous vehicles alike.

However, before drawing far-reaching conclusions from this report, it first needs to be shown in independent replication studies that the effect of visuospatial training on

a Correspondence concerning this article should be addressed to Axel Buchner, Department of Experimental Psychology, Heinrich Heine University Düsseldorf, 40225 Düsseldorf, Germany. Email: axel.buchner@hhu.de

motion sickness is reliable (Open Science Collaboration, 2015). In the present instance, the need for a test of replicability seems particularly relevant because the data reported by Smyth et al. (2021) have several unexpected features.

First, Smyth et al. (2021) assessed visuospatial skill using the Mental Rotation Test (Peters et al., 1995; Vandenberg & Kuse, 1978) both before the first and before the second driving experience. It has long been known that "practice effects are dramatic" (Peters et al., 1995, p. 35) in the Mental Rotation Test (see also Casey & Brabeck, 1989). That is, scores obtained using the Mental Rotation Test increase dramatically when filling out the test twice in succession (Versions A and B of the Mental Rotation Test differ only in the order in which the items are presented, see Peters et al., 1995, p. 48). Yet the scores of participants in Smyth et al.'s (2021) no-training control group were said to have increased only "slightly" (p. 5) from the first visuospatial skill assessment to the second visuospatial skill assessment using the Mental Rotation Test. This assertion seems unexpected given the large practice effects for which the Mental Rotation Test is known. However, a closer look at the data reveals that the increase in the Mental Rotation Test scores of the participants in Smyth et al.'s (2021) no-training control group was in fact 29.2 % and thus quite substantial and not too different descriptively from the 45.8 % increase reported for the visuospatial-training group. Unfortunately, we do not know whether the 45.8 % increase in the Mental Rotation Test score in the visuospatial-training group differs significantly from the 29.2 % increase in the control group because Smyth et al. (2021) did not report the critical statistical test in which these increases were directly compared. We will present arguments below as to why the difference between a 45.8 % increase and a 29.2 % increase almost certainly was not statistically significant, particularly given the small sample size of only $N = 15$ participants in their visuospatial-training group and only $N = 7$ participants in their control group.

Second, in the visuospatial-training group of Smyth et al. (2021) the effect of the visuospatial training was smaller on the visuospatial ability itself (said 45.8 % increase) than on motion sickness (a 58.5 % decrease). Normally one would expect the effect of training an ability to be largest on the trained ability itself (here: visuospatial ability) and smaller on other, less directly related variables (here: motion sickness). In the data reported by Smyth et al. (2021) the pattern is reversed and there is no obvious reason as to why this should be the case.

Third, as mentioned above, the sample size in the study of Smyth et al. (2021) is very small. The total sample size was $N = 22$ and there were only $n_1 = 15$ participants in the visuospatial-training group and even only $n_2 = 7$ participants in the no-training control group in the critical part of their study. The probability of obtaining sample statistics that differ considerably from the underlying population parameters is larger with such a small sample than with larger samples. In addition, no justification was presented as to why the number of participants in the no-training control group was less than half of the number of participants in the visuospatial-training group. Unequal group sizes are normally avoided unless there is a strong reason for it (e.g., the availability of very few participants with a particularly rare problem such as amnesia relative to participants who can serve as controls). The reason for this is that unequal groups sizes introduce an unwanted element of inefficiency into the design. Specifically, unequal group sizes imply a decline of the sensitivity of the statistical tests comparing the groups relative to a design with equal group sizes. To illustrate, the sensitivity of an analysis of variance comparing two groups with $n_1 = n_2 = 11$ participants in each group and thus a total sample size of $N = 22$ participants is already quite low in that an effect has to have the size of $f = 0.81$ to be detected given the usual error probabilities of $\alpha = \beta = .05$. With $n_1 = 15$ participants in one group and $n_2 = 7$ participants in the other group and thus the same total sample size of $N = 22$ the sensitivity declines even further in that, all other things being equal, an effect actually has to have the size of $f = 0,87$ to be detected. In essence, then, a replication with a larger sample seems needed to obtain results that can be expected to yield sample statistics closer to the underlying population parameters.

Fourth, there is no reason for a causal relationship between what is trained—visuospatial skill—and the targeted symptom—susceptibility to motion-sickness. The most popular theory of motion sickness has long been the sensory conflict theory. According to this theory, motion sickness is primarily caused by a mismatch between the expected and the actual interplay among the visual, vestibular and somatosensory senses (Cha et al., 2021; Keshavarz & Golding, 2022). It is unclear how this sensory mismatch might be related, let alone causally related, to a person's ability to mentally rotate two-dimensional drawings of artificial three-dimensional objects composed of wireframe cubes (Shepard & Metzler, 1971), which is what the Mental Rotation Test measures (Peters et al., 1995; Vandenberg & Kuse, 1978). If there is no such causal relation between the cognitive skills needed for mental rotation tasks of the type just described and the mechanisms causing motion sickness, then there is also no reason as to why manipulations of the cognitive skills needed for mental rotation should affect the susceptibility to motion sickness. Smyth et al. (2021) even concede that "the reason for this observed effect [of visuospatial training on motion sickness] is unknown" (p. 9). Although it is of course possible that such a reason may be uncovered in the future, the fact that it is currently unknown why visuospatial training should affect motion sickness is another reason as to why an independent replication of the original study seems desirable.

The goal of the research reported here was to provide an independent conceptual replication of the original study. The present study was modeled after the critical 'Part 2' of the study of Smyth et al. (2021). However, the sample size of the present replication study was considerably larger than that of the original study. To induce motion sickness, a 30-minute simulated drive in a virtual environment was used, covering both rural and urban environments, similar to the environments used in the driving task of Smyth et al. (2021). Participants' visuospatial ability and motion sickness were measured before this drive. Motion sickness was also measured during the drive and thereafter, using the same instruments as those used by Smyth et al. (2021). During the subsequent 14 days, participants in the visuospatial-training group, but not participants in the no-training group, worked on the same problems as the participants in the experimental group of Smyth et al. (2021). Participants returned to the virtual reality laboratory 14 days after the first drive. Their visuospatial ability and motion sickness were again measured before their second drive. Motion sickness was again measured both during the drive and thereafter.

Method

Statistical power considerations and participants

An a priori power analysis using G*Power (Faul et al., 2007) showed that to detect a difference between the visuospatial-training group and the no-training group in the reduction in motion sickness from the first simulated drive to the second simulated drive of size $\eta_p^2 = .15$ given $\alpha = \beta = .05$, $N = 78$ participants were needed. Participants were recruited on campus at Heinrich Heine University Düsseldorf. Our goal was to recruit about 100 participants to still have at least the required sample size available in case a substantial dropout due to motion sickness occured. We were able to recruit 111 participants in the period during which we had a laboratory at our disposal, but 6 participants decided to terminate the experiment prematurely or did not show up for the second drive. The data of 14 of the remaining participants could not be analyzed because they did not fill out the Mental Rotation Test properly (they systematically selected only one of the two correct solutions) or because they were given the wrong form of the Mental Rotation Test (for instance, Form A before the second drive when they had already filled out Form A before the first drive). With data of $N = 91$ participants remaining ($n_1 = 46$ in the visuospatial-training group, $n_2 = 45$ in the no-training group), the sensitivity of the critical statistical test still was even better than we had planned. All other things being equal, we were able to detect a difference of size $\eta_p^2 = .13$ between the visuospatial-training group and the no-training group in the change in motion sickness from the first to the second drive.

The median age of the 67 female and 24 male participants was 22 years (between 18 and 54 years). Most of them (80) were right-handed.

Ethics statement

Participants gave written informed consent prior to participation. They knew that they could terminate their participation in the experiment at any time without any negative consequences for them. The experiments were conducted in line with the Declaration of Helsinki. Approval for the experiment was obtained from the ethics committee of the Faculty of Mathematics and Natural Sciences at Heinrich Heine University Düsseldorf (Case ID ZI01-2021-02).

Materials and procedure

Every potential participant first read a description of the study and the consent form which they signed if they wished to participate. Participants were randomly assigned either to the visuospatial-training group or to the no-training control group. Their self-reported age and gender and their measured handedness (Oldfield, 1971) were recorded and a private code was generated such that data from the first and the second drive and from the various questionnaire measures could later be matched without reference to the participants' identity.

Next, participants received Form A or Form B (randomly determined) of the Mental Rotation Test (Peters et al., 1995; Vandenberg & Kuse, 1978). Subsequently, participants filled out the Simulator Sickness Questionnaire (Kennedy et al., 1993). Participants then received an introduction to the virtual reality equipment after which their first virtual 30-minute drive began.

During the drive, participants were sitting on a chair wearing an HTC Vive Pro headset (with a 1400 × 1600 pixels OLED display per eye and a 90 Hz refresh rate) and holding a Vive motion controller in their right hand. The experiment was controlled by an Intel® i7-based PC with an NVIDIA® RTX 3070 graphics card. The virtual environment was rendered using a custom-made program created in Unreal Engine 4.26 and extensively optimized to run smoothly at 90 frames per second. Head and hand movements were tracked via the headset and the motion controller using the standard SteamVR tracking system.

The drive covered 8.5 km of curvy rural roads with altitude differences of 250 m (15 minutes) followed by about 3.5 km of urban streets with numerous 90-degree turns (15 minutes, Figure 1). The virtual environment was designed to give the impression of sitting in the front passenger's seat of an autonomous left-hand drive passenger car and included features to make this experience convincing such as suitable steering wheel rotations. Once every minute a tone signaled to the participants that they had to rate their motion sickness symptoms using the Fast Motion Sickness Scale (Keshavarz & Hecht, 2011) by selecting, with their index finger, a value between 0 (no sickness at all) and 20 (frank sickness) on a scale displayed on the car's dashboard. After their first response to the Fast Motion Sickness Scale, participants initiated the drive by pressing a start-stop button displayed in the center console of their virtual car. Participants knew that this button could also be used to terminate the drive, for instance in case they experienced motion sickness symptoms beyond the level they were willing to tolerate. Given this, we did not expect motion-sickness symptoms as serious as vomiting. Nevertheless, a bucket was placed to the left of the participants. This bucket was tracked and virtually rendered—it appeared to be placed on the driver's seat—so that participants could locate and use it quickly without needing to remove the headset. None of the participants had to use the bucket.

Immediately after the first drive, participants again filled out the Simulator Sickness Questionnaire. This segment of the experiment took about 45 minutes.

Figure 1. Examples of scenes from the virtual rural environment (upper panel) and from the urban environment (lower panel).

Participants in the visuospatial-training group, but not participants in the no-training control group, subsequently received 14 emails, each on one of the 14 days following the day of the first drive. Each email contained a set of visuospatial problems (the problems listed in Table 1 of Smyth et al., 2021, but translated into German, typeset and edited by the present authors) together with the instruction, parallel to that used by Smyth et al. (2021), to work on the set on the day it had been received for 15 minutes; if participants needed less time to find the solutions to the visuospatial problems they were to fill the remaining time studying their solutions, as in the original study. Participants were instructed to turn in the completed sets with their solutions by email on the same day on which they had solved the problems. The problems of Set 14 were to be solved on the day of the second drive before showing up in the laboratory. Of the 46 (participants) × 14 (days) = 644 sets handed out to the participants, 2 (.003 %) were not turned in at all and 138 (21 %) were turned in on an incorrect day (usually a day too late and then together with the set of that day).

Participants returned to the laboratory 14 days after their first drive. If an interval of exactly 14 days was not feasible for a particular participant, then an appointment was made for the weekday following the day that had originally been planned for that participant. The sequence of events was identical to that of the first drive with two exceptions. First, participants started immediately by filling out the Mental Rotation Test (Form B if they had received Form A before or Form A if they had received Form B before). Second, at the end of the experiment participants were informed about the purpose of the study and were either paid (90 € if they were in the visuospatial-training group and 20 € if they were in the no-training control group) or received course credit for their participation. This segment of the experiment also took about 45 minutes.

Results

The results of the Mental Rotation Test are displayed in Figure 2. A 2 × 2 analysis of variance with test occasion (before the first drive vs. before the second drive) as within-subject independent variable and training (visuospatial training vs. no training) as between-subjects independent variable showed a main effect of test occasion, $F(1, 89) = 44.733$, $p < .001$, $\eta_p^2 = .334$, no main effect of training, $F(1, 89) = 0.352$, $p = .554$, $\eta_p^2 = .004$, and no interaction between these variables, $F(1, 89) = 0.541$, $p = .464$, $\eta_p^2 = .006$. Thus, there was the expected practice effect in that participants improved substantially from the first to the second time they took one of the two versions of the Mental Rotation Test (Peters et al., 1995) but the critical interaction between the test-occasion variable and the training variable was not significant: The improvement in the Mental Rotation Test score was only descriptively, but not significantly, larger in the visuospatial-training group than in the no-training group. Unfortunately, we cannot compare this statistical test result to the corresponding result from Smyth et al. (2021) because they did not report the critical statistical interaction test. However, a comparison of the results at a descriptive level can be done and is in fact quite instructive. We found that the visuospatial-training group and the no-training group improved from the first test occasion before the first drive to the second test occasion before the second drive by 49.8 % and 35.4 %, respectively. Smyth et al. (2021, p. 5) reported improvements of 45.8 % and 29.2 % for their visuospatial-training group and their no-training group, respectively. Given the striking similar-

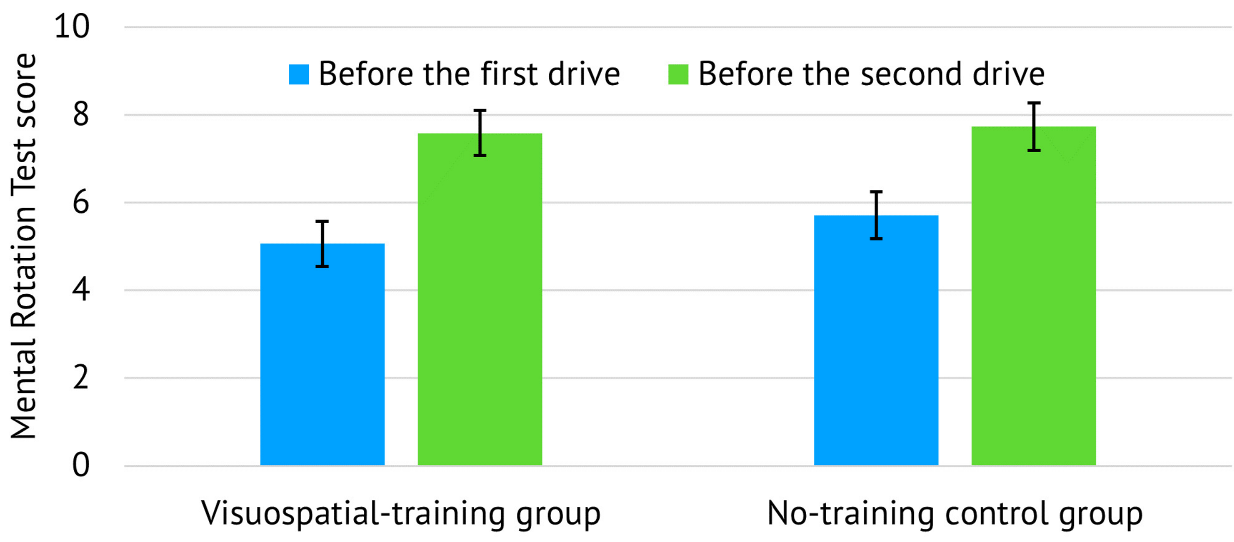

Figure 2. Mean Mental Rotation Test score before the first drive and before the second drive.

Note: Error bars show standard errors.

ity of these data combined with the fact that Smyth et al. (2021) had only n_1 = 15 and n_2 = 7 participants in their visuospatial-training group and their no-training group, respectively (and, thus, very little statistical power in their test of an interaction between the test occasion and training variables), it seems safe to extrapolate that the non-reported critical interaction based on the data of Smyth et al. (2021) was most likely not statistically significant.

An obvious question is why there was not more of a training effect on the Mental Rotation Test score in the visuospatial-training group apart from the to-be-expected practice effect itself (Peters et al., 1995). This question will be dealt with in the Discussion section. To anticipate, it seems intuitively plausible that it should be quite difficult to augment an effect as large as the practice effect observed with the Mental Rotation Test. Also, a closer look at the visuospatial training problems used by Smyth et al. (2021) as well as here reveals that there is surprisingly little overlap between what is practiced in these visuospatial training problems and what the Mental Rotation Test measures.

Next, we analyzed whether participants developed motion sickness during the simulated drives. For that purpose, the total score of the Simulator Sickness Questionnaire before each drive was subtracted from the total score of the Simulator Sickness Questionnaire after each drive. Positive differences indicate an increase in motion sickness during the drive. Figure 3 shows, and a statistical test confirms, that collectively these differences were significantly above zero, $F(1, 89) = 70.392$, $p < .001$, $\eta_p^2 = .442$. In other words, participants developed motion sickness during the simulated drives. A 2 × 2 analysis of variance with test occasion (during the first drive vs. during the second drive) as within-subject independent variable and training (visuospatial training vs. no training) as between-subjects independent variable showed a main effect of test occasion, $F(1, 89) = 19.392$, $p < .001$, $\eta_p^2 = .179$, no main effect of training, $F(1, 89) = 2.052$, $p = .156$, $\eta_p^2 = .023$, and, importantly, no interaction between these variables, $F(1, 89) = 0.016$, $p = .900$, $\eta_p^2 < .001$.

In addition, we analyzed participants' responses to the Fast Motion Sickness Scale. The average Fast Motion Sickness Scale score is presented in Figure 4. A 2 × 2 analysis of variance with test occasion (during the first drive vs. during the second drive) as within-subject independent variable and training (visuospatial training vs. no training) as between-subjects independent variable showed a main effect of drive, $F(1, 89) = 44.426$, $p < .001$, $\eta_p^2 = .333$, no main effect of training, $F(1, 89) = 0.414$, $p = .522$, $\eta_p^2 = .005$, and, importantly, no interaction between these variables, $F(1, 89) = 1.349$, $p = .249$, $\eta_p^2 = .015$. These results consistently show that participants habituated considerably to the motion sickness inducing drive in the virtual reality environment from the first drive to the second drive. However, this habituation was not modulated by whether participants had performed 14 days of visuospatial training or not.

The data of the experiment and the virtual scenario as well as supplementary Bayesian analyses pertaining to the interactions between test occasion (first drive vs. second drive) as within-subject independent variable and training (visuospatial training vs. no training) as between-subjects independent variable for each of the three dependent variables considered above are available at the OSF project page (see the Data Acessibility Statement at the end of the article). In essence, the results of the Bayesian analyses amount to clear evidence in favor of the null hypothesis of no interaction between test occasion and training with respect to the Mental Rotation Test score, BF_{01} = 11.131, the total score of the Simulator Sickness Questionnaire, BF_{01} = 6.747, and the Fast Motion Sickness Scale score, BF_{01} = 7.075.

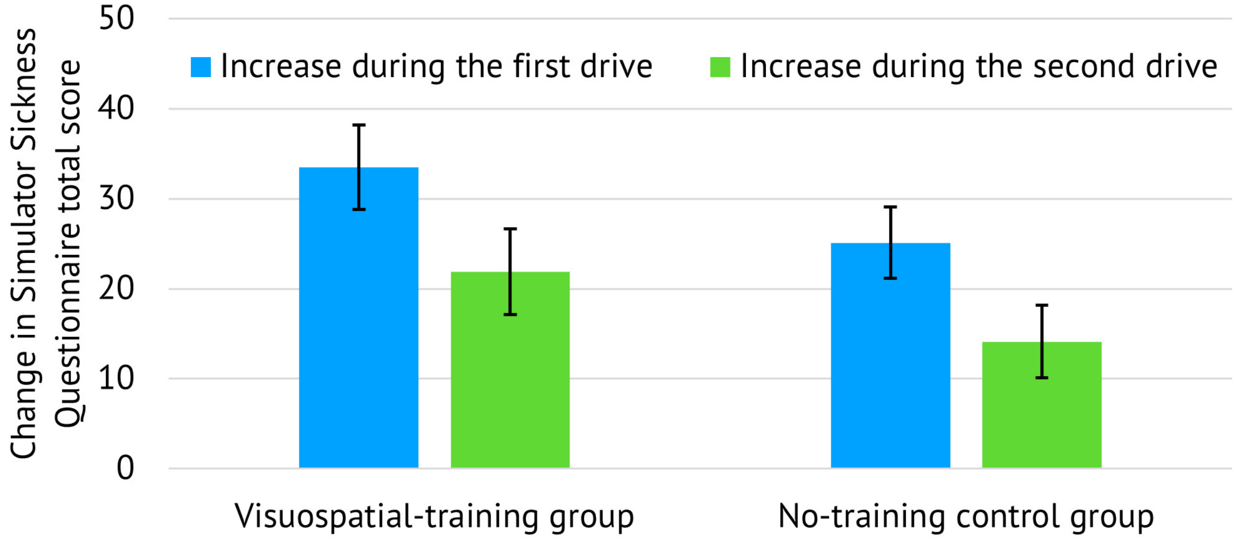

Figure 3. Mean increase in the total score of the Simulator Sickness Questionnaire during the first drive and during the second drive

Note: Error bars show standard errors.

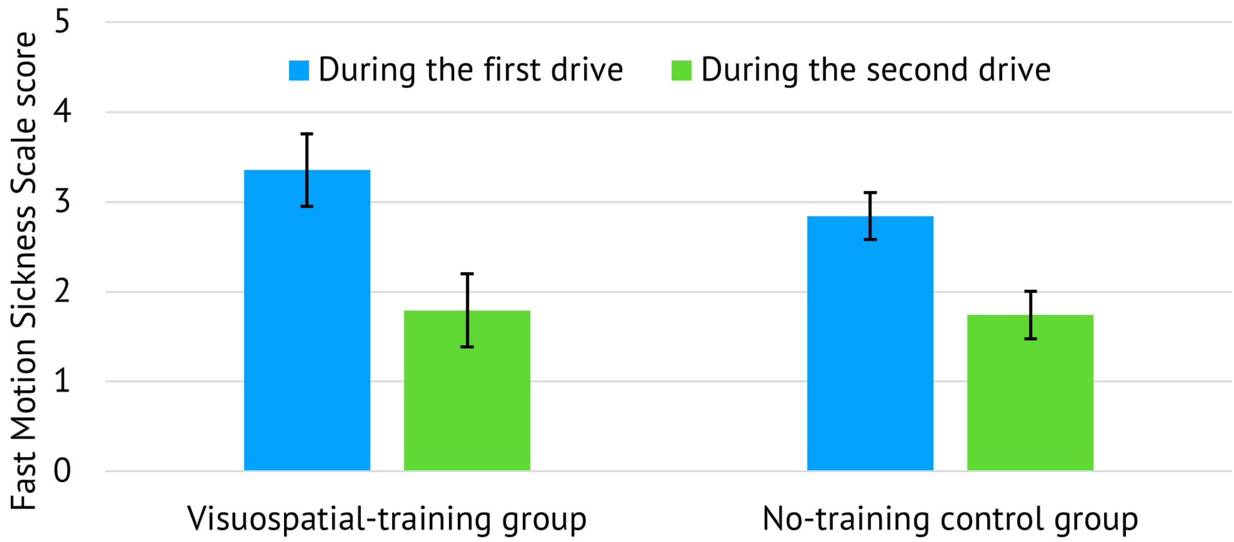

Figure 4. Mean Fast Motion Sickness Scale score during the first drive and during the second drive.

Note: Error bars show standard errors.

Discussion

The results of the present conceptual replication of the study by Smyth et al. (2021) are unequivocal. Whereas both the typical practice effect in the Mental Rotation Test (Peters et al., 1995) and the typical habituation of the susceptibility to motion sickness (Keshavarz & Golding, 2022) were observed, none of the key findings of Smyth et al. (2021) were replicated: The visuospatial training affected neither the Mental Rotation Test score nor the susceptibility to motion sickness. This result is remarkable considering that the sample size and, thus, the sensitivity of the statistical tests was much larger in the present study ($N = 91$) than in that of Smyth et al. (2021) ($N = 22$).

The failure to replicate the key findings of Smyth et al. (2021) must be seen in the context of several unexpected features of the data they reported, as discussed in the introduction. First, Smyth et al. (2021) reported an improvement of 45.8 % and 29.2 % in their visuospatial-training group and their no-training control group, respectively, but they did not report the critical statistical test of whether the difference in improvement between groups is statistically significant. Our analysis of this pattern (presented in the Results section) has demonstrated that this difference was most likely not statistically significant. Second, in the visuospatial-training group the effect of the visuospatial training was smaller on the visuospatial performance itself (a 45.8 % increase) than on motion sickness (a 58.5 % decrease). It is unexpected that the effect of training an ability was smaller on the trained ability itself than on another, less directly related variable. Third, Smyth et al. (2021) had only n_1 = 15 participants in the visuospatial-training group and even only n_2 = 7 participants in the no-training control group in the critical part of their study. It is well-known that the probability of obtaining sample statistics that differ considerably from the underlying population parameters is larger with such a small sample than with larger samples. In addition, no justification was presented as to why an element of inefficiency was introduced into the design by having less than half the number of participants in the no-training control group relative to the number of participants in the visuospatial-training group. Fourth, there is no reason as to why visuospatial skill should be related, let alone causally related, to motion sickness. Smyth et al. (2021, p. 9) have conceded this fact which means that there is currently no reason to assume that manipulations of the cognitive skills needed for mental rotation should have an effect on the susceptibility to motion sickness. The present data are compatible with the conclusion that this effect does not exist.

A possible problem common to the study reported here and that of Smyth et al. (2021) is that the improvement in the Mental Rotation Test was only descriptively, but not significantly larger in the visuospatial-training group relative to the no-training group. As mentioned above, in the Mental Rotation Test “practice effects are dramatic” (Peters et al., 1995, p. 35) both in general and in the data reported here. It seems intuitively plausible that it should be quite difficult to augment an effect that is already dramatic. What is more, the Mental Rotation Test consists of variants of the rotation problems used by Shepard and Metzler (1971), that is, of two-dimensional presentations of three-dimensional objects composed of ‘wireframe’ cubes that need to be rotated and then matched to other two-dimensional presentations of three-dimensional objects composed of ‘wireframe’ cubes. It is well-known that mentally rotating such objects can be improved when the training task involves rotating these very same objects (e.g., Heil et al., 1998; Jost & Jansen, 2021; Wiedenbauer et al., 2007; Wiedenbauer & Jansen-Osmann, 2008). Importantly, a closer look at the training problem sets used by Smyth et al. (2021, see their Table 1) and, therefore, in the present conceptual replication study reveals that none of these problems resemble the problems used in the Mental Rotation Test. In fact, six problem sets (Sets 1, 2, 6, 9, 12 and 13) do not even contain a single three-dimensional problem; the problems in these sets are exclusively two-dimensional. Two more sets (Sets 5 and 11) consist of both two-dimensional and three-dimensional problems and six sets (Sets 3, 4, 7, 8, 10 and 14) consist of three-dimensional problems. In other words, the mental routines necessary to solve the training problems overlap only partially with the mental routines necessary to solve the problems of which the Mental Rotation Test consists. It should thus not come as a surprise that there is very little positive transfer from these training problems to the Mental Rotation Test. In sum, then, the fact that the so-called visuospatial training did not affect performance in the Mental Rotation Test more than it did is not surprising at all but rather is to be expected.

A deviation of the present study from that of Smyth et al. (2021) is that the drives occurred in a virtual-reality environment whereas the participants in the original study were driven around. However, from a pragmatic point of view it seems important to note that the critical construct here is motion sickness and, as the data reported above show, participants developed substantial motion sickness. From a theoretical point of view, sensory conflict theory implies that motion sickness is primarily caused by a mismatch between the expected and the actual interplay among the visual, vestibular and somatosensory senses (Cha et al., 2021; Keshavarz & Golding, 2022). Simply put, in the driving task used by Smyth et al. (2021) in which participants were driven around while reading text in the backseat of a car, the visual signal implied little motion of the body whereas the vestibular and somatosensory signals implied motion, creating a mismatch compared to the normal interplay between these senses. In the simulated drive in a virtual environment used here, the vestibular and somatosensory signals implied less motion of the body than the visual signal, again creating a mismatch compared to the normal interplay between these senses. Thus, the crucial mismatch occurs in both types of situations and, expectedly, the motion sickness symptoms occurring in both types of situations are essentially the same (Cha et al., 2021). The sensory mismatch theory also implies that motion sickness should be reduced as a function of repeated exposure due to habituation, that is, because “the internal model of expected input recalibrates” (Cha et al., 2021, p. 329) and the organism learns, within the limits of its adaptive capacity, to expect the previously unexpected interplay among the visual, vestibular and somatosensory senses.

In sum, Smyth et al. (2021, p. 9) have conceded that there is no reason why manipulating the amount of practice in solving two-dimensional and three-dimensional visuospatial matching problems should affect the susceptibility to motion sickness, and we did not observe such an effect despite the fact that the sample size and, hence, the sensitivity of the statistical tests in the present study were much larger than their counterparts in the study by Smyth et al. (2021). Given this, it is probably prudent to assume that the effect does not exist and to continue to rely on the conclusion reached by Keshavarz and Golding (2022, p. 107) that “habituation remains the most effective nonpharmacological method to reduce motion sickness”.

Contributions

Contributed to conception and design: MW, EZ, ES, AB
Contributed to acquisition of data: MW, AB
Contributed to analysis and interpretation of data: MW, EZ, ES, AB
Drafted and/or revised the article: MW, EZ, ES, AB
Approved the submitted version for publication: MW, EZ, ES, AB

Competing Interests

We have no competing interests to disclose.

Data Accessibility Statement

The data of the experiment and the virtual scenario as well as the results of the supplementary Bayesian analyses are available at https://osf.io/4deuq/?view_only=baf13d4ece2d4949b9bea310274280da

Submitted: August 14, 2023 PDT, Accepted: June 18, 2024 PDT

References

Bagloee, S. A., Tavana, M., Asadi, M., & Oliver, T. (2016). Autonomous vehicles: challenges, opportunities, and future implications for transportation policies. *Journal of Modern Transportation*, *24*(4), 284–303. https://doi.org/10.1007/s40534-016-0117-3

Casey, M. B., & Brabeck, M. M. (1989). Exceptions to the male advantage on a spatial task: Family handedness and college major as factors identifying women who excel. *Neuropsychologia*, *27*(5), 689–696. https://doi.org/10.1016/0028-3932(89)90113-9

Cha, Y.-H., Golding, J. F., Keshavarz, B., Furman, J., Kim, J.-S., Lopez-Escamez, J. A., Magnusson, M., Yates, B. J., Lawson, B. D., Staab, J. P., & Bisdorff, A. (2021). Motion sickness diagnostic criteria: Consensus Document of the Classification Committee of the Barany Society. *Journal of Vestibular Research: Equilibrium & Orientation*, *31*(5), 327–344. https://doi.org/10.3233/VES-200005

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates. https://doi.org/10.4324/9780203771587

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Heil, M., Rösler, F., Link, M., & Bajric, J. (1998). What is improved if a mental rotation task is repeated – the efficiency of memory access, or the speed of a transformation routine? *Psychological Research*, *61*(2), 99–106. https://doi.org/10.1007/s004260050016

Jost, L., & Jansen, P. (2021). Manual training of mental rotation performance: Visual representation of rotating figures is the main driver for improvements. *Quarterly Journal of Experimental Psychology*, *75*(4), 695–711. https://doi.org/10.1177/17470218211039494

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, *3*(3), 203–220. https://doi.org/10.1207/s15327108ijap0303_3

Keshavarz, B., & Golding, J. F. (2022). Motion sickness: current concepts and management. *Current Opinion in Neurology*, *35*(1), 107–112. https://doi.org/10.1097/wco.0000000000001018

Keshavarz, B., & Hecht, H. (2011). Validating an efficient method to quantify motion sickness. *Human Factors*, *53*(4), 415–426. https://doi.org/10.1177/0018720811403736

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4

Open Science Collaboration. (2015). Estimating the reproducibility of psychological science. *Science*, *349*, aac4716. https://doi.org/10.1126/science.aac4716

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn Vandenberg and Kuse Mental Rotations Test: Different versions and factors that affect performance. *Brain and Cognition*, *28*(1), 39–58. https://doi.org/10.1006/brcg.1995.1032

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, *171*(3972), 701–703. https://doi.org/10.1126/science.171.3972.701

Smyth, J., Jennings, P., Bennett, P., & Birrell, S. (2021). A novel method for reducing motion sickness susceptibility through training visuospatial ability – A two-part study. *Applied Ergonomics*, *90*. https://doi.org/10.1016/j.apergo.2020.103264

Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, *47*(2), 599–604. https://doi.org/10.2466/pms.1978.47.2.599

Wiedenbauer, G., & Jansen-Osmann, P. (2008). Manual training of mental rotation in children. *Learning and Instruction*, *18*(1), 30–41. https://doi.org/10.1016/j.learninstruc.2006.09.009

Wiedenbauer, G., Schmid, J., & Jansen-Osmann, P. (2007). Manual training of mental rotation. *European Journal of Cognitive Psychology*, *19*(1), 17–36. https://doi.org/10.1080/09541440600709906

Supplementary Materials

Peer Review Communication

Download: https://collabra.scholasticahq.com/article/121390-visuospatial-training-does-not-reduce-motion-sickness-susceptibility/attachment/236899.docx?auth_token=dWzRomQ-lfPcTJBZr4BN

Response Letter

Download: https://collabra.scholasticahq.com/article/121390-visuospatial-training-does-not-reduce-motion-sickness-susceptibility/attachment/236900.pdf?auth_token=dWzRomQ-lfPcTJBZr4BN