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# Mitigating Simulator Adaptation Syndrome by means of tactile stimulation

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ABSTRACT

Some drivers experience Simulator Adaptation Syndrome (SAS), a condition in which nausea, disorientation, dizziness, headache, and difficulty focusing, are exhibited when driving in a simulator. To reduce this syndrome, we investigated the efficacy of tactile stimulation (TS) on mitigating Simulator Adaptation Syndrome (SAS) in a driving simulation. Fifteen drivers (eight women; mean age = 24.07 years) participated in this experiment. We compared the total scores of the Simulator Sickness Questionnaire (SSQ) across two stimulation conditions (TS condition and no stimulation condition as a baseline measure). The experimental outcomes revealed that TS seemed to decrease SAS due to attentional distraction from the symptoms and not because of an improvement in balance ability.

## 1. Introduction

Simulator Adaptation Syndrome (SAS) is a condition that occurs due to a mismatch between sensory inputs regarding position and what is expected in driving simulators. This syndrome can range from mild discomfort to severe dry mouth, drowsiness, disorientation, vertigo, nausea, dizziness, and vomiting (Ebenholtz, 1992; Cobb et al., 1999). The aetiology of SAS is not completely understood (see Mollenhauer, 2004; for an extensive review of SAS). As Cox et al. (2011) show, the causes of this syndrome can be assembled attending to individual factors (e.g., age), characteristics of the driving simulator (e.g., size of the display screen), and the individual's interaction with the simulator (e.g., exposure time).

To counterbalance this syndrome, some studies focus on mitigating SAS using drugs. The use of drugs (for a review, see Sherman, 2002) is not an efficient countermeasure to mitigate SAS due to side effects that may affect training efficiency (Murdin et al., 2011). First, studies with scopolamine may cause sedation, dry mouth, blurring of vision, and light-headedness (Crowley, 1987). Secondly, oral medication for SAS reduces gastric motility (Wood et al., 1987). Finally, it should be noted that medications do not reach their efficacy until several hours after administration. Considering these problems, alternative techniques have emerged to mitigate SAS using different sources of stimulation, like galvanic cutaneous stimulation (GCS), galvanic vestibular stimulation (GVS) and, more recently, auditory stimulation (AS). GCS restores normal balance in the context of vestibular sensory deprivation, as in fixed-simulators. For example, Reed-Jones et al. (2008), and Gálvez-García (2015) show that the application of GCS improves balance in subjects performing a simulator task. The improvement in balancing ability is correlated with the mitigation of SAS (Gálvez-García (2015)). In addition, three studies show the positive impact of GCS on SAS (Chu et al., 2013; Gálvez-García, 2015; Gálvez-García et al., 2015). GVS is a similar technique to GCS. This involves providing vestibular motion stimuli to reduce SAS. It is shown that GVS improves the body's balance (e.g., Inglis et al., 1995) and, more importantly, reduces SAS (Reed-Jones et al., 2007). AS (more concretely, white noise) has been recently shown to be an efficient technique to mitigate SAS. Gálvez-García (2015) shows that white noise improves balance in subjects performing a simulator task. Moreover, the improvement in balancing ability correlates with the mitigation of SAS. This finding supports the idea that white noise

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*Abbreviations:* SAS, Simulator Adaptation Syndrome; GCS, galvanic cutaneous stimulation; GVS, galvanic vestibular stimulation; AS, auditory stimulation; TS, tactile stimulation.

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improves body stability in patients with vestibular problems (Mangiore, 2012). More importantly there is evidence that supports that white noise functions as a countermeasure to decrease SAS (Gálvez-García, 2015).

The aforementioned techniques (GCS, GVS and white noise) have a positive impact on balance ability, decreasing SAS. Interestingly, this constitutes direct evidence in support of the postural instability theory (Riccio and Stoffregen, 1991), where it has been postulated that SAS is produced by an inability to learn how to maintain postural stability. Nevertheless, the mitigation of SAS could come from other sources, especially considering that the aetiology of this phenomenon is not entirely clear and could be due to several reasons. As the main aim of this research, we want to test an additional source of stimulation that does not affect balance ability as a possible countermeasure to decrease SAS: distraction from sickness. Thus, a source of stimulation that does not deteriorate driving performance will reduce participants' awareness of SAS symptoms (i.e., stomach discomfort, eyestrain, etc.). This hypothesis is based in previous evidence. For example, Reed-Jones (2011) compares a condition of unilateral and congruent GVS (reflecting what the participants can feel during a curve in naturalistic situations) with the opposite situation (unilateral stimulation that provided the opposite vestibular experience). He shows a similar pattern of results in both conditions, concluding that electrical stimulation can distract from the sickness and cause a decrease in SAS. In addition, this attentional disengagement hypothesis can explain, for example, why different types of stimulation, like acupuncture, decrease SAS (e.g., Wesley and Tengler, 2005). Nevertheless, it is important to remark that this explanation based on distraction would be additive to the aforementioned literature supporting the idea of motion induced by a different form of stimulation (e.g., GCS and AS) as the cause of SAS mitigation. Thus, the attentional disengagement hypothesis can coexist with evidence regarding the increase of postural control to mitigate SAS. We want to remark that testing the attentional disengagement hypothesis is crucial in order to provide evidence of SAS as a multifactorial syndrome, which can be dealt with via several different countermeasures. In order to test the attentional disengagement hypothesis, we study how tactile stimulation (TS) influences SAS, as TS is not shown as bothersome in previous studies on tactile attention (e.g., Gálvez-García et al., 2012a; Gálvez-García et al., 2012b). This is crucial in order to avoid a decline in any driving variable, which could be controversial in terms of future recommendations of the technique. We aim to deliver TS on the quadriceps to avoid stimulating the muscles of the trunk or neck, which may fortuitously provide data to the central nervous system on the position of the trunk and head in space. The TS must only affect attentional processes in order to test the attentional hypothesis. In any case, we aim to measure how TS affects body balance to rule out this issue as an explanatory factor of the pattern of results. For this purpose, we measure head postural stability (head sway) as a measure of balance in line with previous research (Easton et al., 1998; Gálvez-García, 2015; Reed-Jones, 2011). Finally, it should be noted that TS is an inexpensive and simple technique to mitigate SAS (i.e., the application of TS only requires a tactile device synchronised with the simulator to provide a tactile signal during curves), which is fundamental for the recommendation of this technique for future interventions to reduce SAS.

An additional aim of this research is to investigate how TS affects driving performance. Previous research (Gálvez-García, 2015; Gálvez-García et al., 2015; Reed-Jones et al., 2009) had failed to find an effect of external techniques that decrease SAS (i.e., GCS and auditory stimulation) on driving performance.

We hypothesise that TS will improve SAS without a positive impact on balancing ability, attending to the attentional distraction from sickness.

## 2. Method

### 2.1. Participants

We used a similar method previously described by Gálvez-García (2015). Prior to the experiment, participants completed the Motion Sickness Susceptibility Questionnaire (MSSQ; Golding, 1998) to determine if they had a predisposition to motion sickness. Participants with MSSQ scores higher than 65 (75th percentile) were not included in the experiment because of their susceptibility to sickness (no participants were excluded; mean MSSQ score for our sample was 39.35 ± 19.07). The participants included 7 men and 8 women (mean age = 24.07 ± 2.84 years). To be included in this study, participants should have driven at least 3000 km the previous year, should not have a pacemaker or a hearing aid, should never have experienced vestibular vertigo, and finally, should not be taking medicines that affect driving. All participants reported normal or corrected-to-normal vision and normal tactile perception. Participants were instructed to refrain from the use of medication, alcoholic substances, and caffeinated drinks for 24 h before the experiment. Participants were unaware of the purpose of the experiment, received a six Euro gift voucher in return for their participation, and gave their signed informed consent. All procedures were in accordance with the declaration of Helsinki and the ethical standards of the human research advisory committee.

### 2.2. Apparatus and stimuli

TS was delivered during the curves by a small metallic rod for a duration of 5 ms, and each stimulation followed a protocol similar to Gálvez-García et al. (2012a, 2012b).

The study was carried out in an instrumented fixed-base simulator with sensors on the pedals, wheels and gearbox. A high-speed digital camera (S-MOTION) was used to record head movements. On a 7.5 km flat route through an urban environment, participants negotiated 18 curves (nine lefts and nine rights) – gradual or sharp 90° turns. The gradual turns (GTs) consisted of a 70 m lead-in, a 140 m curve, and a 70 m lead-out (240 m in total). The sharp turns (STs) were modelled on a T-junction and consisted of a 40 m lead-in, and a 40 m curve transitioning immediately to the next road (80 m in total) (see Gálvez-García, 2015 for more details about the scenario).

### 2.3. Procedure

Participants performed a driving session (5 min) to become familiar with the car at the beginning of the experiment. After this familiarisation, participants drove the experimental circuit. All participants were asked to drive in the right lane, not to exceed 90 km/h and to reduce their speed during curves in order to perform this manoeuvre efficiently. Participants drove through the simulation two times, corresponding to the two experimental conditions (counterbalanced between participants to compensate for any learned behaviour). These experimental conditions were the following: 1) no stimulation condition, whereby no stimulation was delivered (baseline condition); 2) TS condition, where TS was delivered from 40 m before a curve to the end of the curve. The tactile tappers were placed in position on every subject at the beginning of the experiment to maintain the same set-up across the different experimental conditions. After each drive, participants exited the vehicle for a rest period of 5 min and completed the SSQ. We measured SAS using the Simulator Sickness Questionnaire

(SSQ; Kennedy et al., 1993). The questionnaire was composed of 16 symptoms that the participant had to rate on a scale from none (0) to severe (3). We analysed the SSQ total scores provided by the questionnaire in the two different stimulation conditions.

### 2.4. Design

The different conditions for delivering the stimulation were manipulated as the independent variable (no stimulation, TS). SSQ total scores were measured as the dependent variable. The exclusion criterion was an SSQ total score of more than 2.5 standard deviations (SDs) from the mean. No data were excluded from the analysis. In addition, head sway was measured as a dependent variable. This was defined following previous studies (Gálvez-García, 2015) as the SD of head movements (measured in pixels) along the X- and Y-axes during the curves in the two experimental conditions. Finally, four driving variables were measured to assess the differences in driving behaviour between the two experimental conditions: average speed (km/h); accelerator percentage (percentage of depression of the accelerator pedal); brake percentage (percentage of depression of brake pedal) and SD of the steering variability angle during the curves.

Shapiro–Wilk tests confirmed that all variables were normally distributed. SSQ total scores; W = 0.97, $p = 0.86$, head sway along the X-axis; W = 0.95, $p = 0.57$, head sway along the Y-axis; W = 0.94, $p = 0.40$, average speed; W = 0.95, $p = 0.57$, accelerator percentage; W = 0.97, $p = 0.86$, brake percentage; W = 0.96, $p = 0.71$, SD of the steering variability angle; W = 0.97, $p = 0.86$. Repeated measures (within factor) ANOVA were used to compare SSQ total scores, head sway and driving performance variables in the two stimulation conditions. The eta-square ($\eta^2$) was also calculated to provide a measure of effect size In order to decrease the overall probability of Type I errors, we included Bonferroni corrections of the significance level in each comparison. Results were, therefore, considered significant at $p < 0.05/4$, i.e. $p < 0.0125$ (driving performance variables; four ANOVAs were carried out for these variables) or $p < 0.05/2$, i.e. $p < 0.025$ (head sway; two ANOVAs).

## 3. Results

### 3.1. SSQ scores

For SSQ total scores, a significant effect for the experimental condition was found ($F(1,14) = 20.77$, $p < 0.001$, $\eta^2 = 0.59$), with significantly higher scores in the no stimulation condition (60) than in the TS (35) (See Fig. 1).

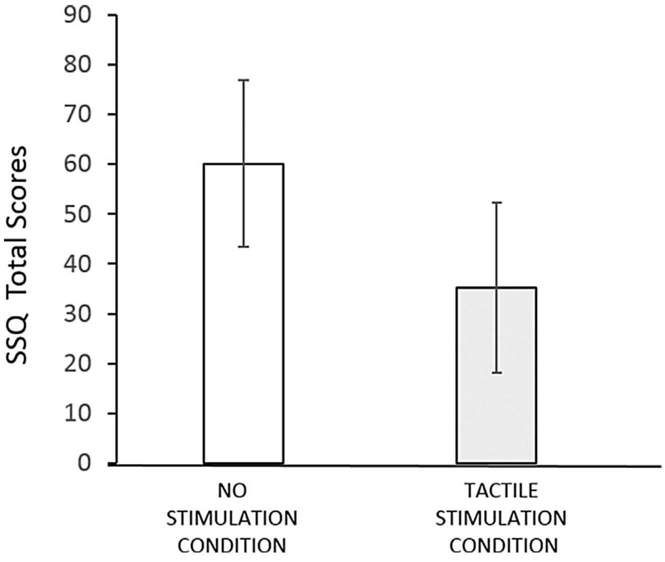

**Fig. 1.** Mean and standard error for post-drive SSQ total score and comparison between experimental conditions.

### 3.2. Head sway

There was no difference between the no stimulation condition (12.52) and the TS condition (12.16) along the X-axis ($F(1,14) = 0.30$, $p = 0.59$, $\eta^2 = 0.02$). There was no difference between the conditions in head sway along the Y-axis ($F(1,14) = 1.27$, $p = 0.28$, $\eta^2 = 0.08$; 4.89 and 4.44 for no stimulation condition and TS condition respectively) (see Fig. 2).

### 3.3. Driving performance variables

Data on driving performance are presented in Table 1. We did not find any differences between conditions.

## 4. Discussion

This research had two aims. First, we wanted to test whether TS could distract attention from the sense of sickness and cause a decrease in SAS. In addition, we wanted to investigate how TS affected different driving variables.

The results confirmed that TS mitigated SAS. When we compare the SSQ total scores in the no stimulation condition (60) vs. the TS condition (35), a significant improvement of 41% was found. It should be noted that SSQ scores above 20 indicated significant discomfort (Webb et al., 2009) and, in our experiment, SSQ total scores for TS was 34, which reflected that, although TS mitigated SAS symptoms, they did not fully disappear. Previous studies showed a larger symptom reduction using techniques that affect balance ability (i.e., AS for head sway; Gálvez-García, 2015) in line with postural instability theory (Riccio and Stoffregen, 1991). This reflected that, to reduce SAS, an improvement in balance ability should be at least considered. In the current study, there was no significant improvement in balance ability when TS was applied when compared with the no stimulation condition (12.52 and 12.16, respectively). Nevertheless, an important finding arose from the reduction of SAS with TS; it was possible to reduce SAS without the aforementioned improvement in body balance. We strongly believed that this was due to the subjects being distracted from the symptoms; the stimulation could have distracted the participants from being conscious of their sickness. More concretely, given that the perception of discomfort was prominent in the conscious experience, electric stimulation could have simply made participants less aware of their knowledge of SAS symptoms (i.e., stomach discomfort, eyestrain, etc.; Reed-Jones, 2011). As we mentioned in the Introduction, this could have partially explained why the stimulation with acupuncture (here, we do not differentiate between acupressure, acupuncture and electroacupuncture) decreased motion sickness symptoms of nausea and vomiting (Stern et al., 2001; Warwick-Evans et al., 1991) and, more specifically, SAS (Cox et al., 2011; Wesley and Tengler, 2005). In addition to the attentional disengagement hypothesis, other attentional factors could co-exist. For example, Seno et al. (2009, 2011) found that the severity of the induced self-motion sensation produced by visual simulation could be moderated by attention. Therefore, as Reed-Jones (2011) implied, the distraction produced by stimulation could reduce the sensation of motion and limit conflict between visual and the other senses. Another attentional factor that could

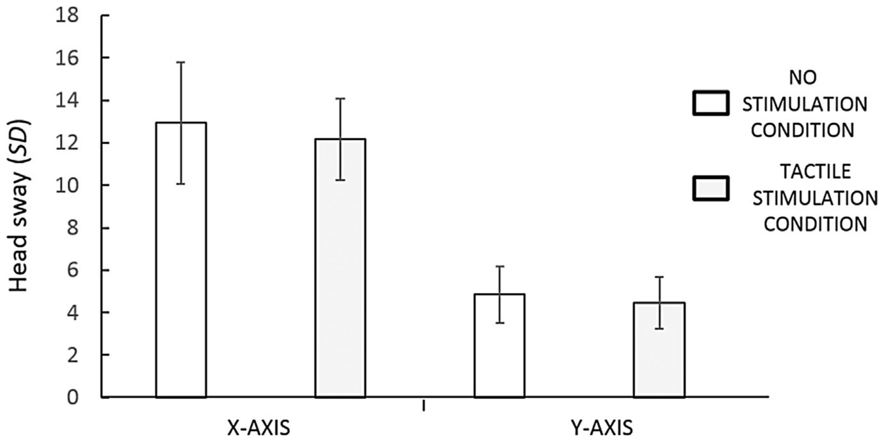

**Fig. 2.** Mean and standard error for head sway and comparison between experimental conditions.

**Table 1**
Driving performance variables (average speed, accelerator percentage, brake percentage and steering variability angle) and comparison between experimental conditions.

| | | |
|---|---|---|
| | **Average speed (km/h)** | **Accelerator percentage (%).** |
| | F(1,14) = 0.61, p = 0.45, n2 = 0.04 | F(1,14) = 0.73, p = 0.64, n2 = 0.03 |
| No stimulation condition | 62,73 | 16,52 |
| Tactile stimulation condition | 58,33 | 16,88 |
| | **Brake percentage (%)** | **Steering variability angle (*SD*)** |
| | F(1,14) = 1.01, p = 0.33, n2 = 0.07 | F(1,14) = 2.34, p = 0.15, n2 = 0.14 |
| No stimulation condition | 7,12 | 999,20 |
| Tactile stimulation condition | 6,82 | 916,96 |

influence the mitigation of SAS is the improvement of this cognitive process through stimulation (any type). For example, Chu et al. (2013) found that simulator exposure increased SAS and decreased concentration, showing that GCS was a good countermeasure to enhance concentration, as the participants made fewer cognitive test errors. In short, it was shown that the attentional disengagement hypothesis and, more generally, attentional factors could be a plausible explanation for SAS. As we have pointed out before, this explanation could coexist with other possible explanations (i.e., postural instability theory; Riccio and Stoffregen, 1991). In any case, our pattern of data showed that SAS was not a simple phenomenon that only affected body balance factors, but also other processes, such as attention. Future interventions could combine different sources of stimulation that affect SAS improving body balance (e.g., GCS and AS) and attentional factors, such as TS. It might be possible to combine all those effects to minimise SAS.

The driving performance variables showed no difference between the no stimulation and TS conditions. This finding was in line with previous literature that did not show any significant driving performance variable differences when several techniques were applied, like GCS (Gálvez-García, 2015; Gálvez-García et al., 2015; Reed-Jones et al., 2009) and white noise (Gálvez-García, 2015). In any case, it is important to note that TS did not adversely affect any driving variable, which is a fundamental point for its recommendation for future interventions reducing SAS.

Finally, we conclude by highlighting the applicability of our research. We have corroborated TS as efficient countermeasures at reducing the effects of SAS in a fixed-base simulator. The beneficial effects of this economical and easily accessible technique should aid researchers in implementing best practises for participants receiving simulator-based training. The identification of attention-related factors as a potential explanation of how different sources of stimulation may reduce simulator sickness is fundamental. Here, if one of the keys to mitigating SAS is to make participants less aware of their symptoms, a wide range of stimulating devices could easily be used and integrated into the simulation setup. Nonetheless, it should be highlighted that the intensity of the stimuli signal should lightly distract attention from the symptoms because otherwise, it might deteriorate driving performance.

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