COMPARING TECHNIQUES TO REDUCE SIMULATOR ADAPTATION SYNDROME AND IMPROVE NATURALISTIC BEHAVIOUR DURING SIMULATED DRIVING

James G. Reed-Jones[1], Rebecca J. Reed-Jones[2], Lana M. Trick[1],
Ryan Toxopeus[1], & Lori A. Vallis[2]
[1]Department of Psychology, University of Guelph
[2]Department of Human Health and Nutritional Sciences, University of Guelph
Guelph, Ontario, Canada
Email: jjones04@uoguelph.ca

Summary: Electrical stimulation of the vestibular sensory system during virtual environment simulations reduces the incidence of simulator adaptation syndrome (SAS). However, interactions between vestibular stimulation and complex visual scenery can increase oculomotor symptoms. This study examined an alternative technique to reduce symptoms of SAS using the application of galvanic cutaneous stimulation of the neck. The effect of both vestibular and cutaneous stimulation was also evaluated on the naturalistic driving behaviour of curves. Thirty participants drove a rural setting virtual environment with high visual cues. Three groups of ten participants each were used to compare the effect of galvanic vestibular stimulation and galvanic cutaneous stimulation versus a control group on post drive scores of the SSQ (Simulator Sickness Questionnaire) and three driving variables (steering variability, lane position, and vehicular speed). Galvanic cutaneous stimulation while driving resulted in decreased SSQ scores, but did not show an effect on driving behaviour. Conversely, galvanic vestibular stimulation while driving curves resulted in vehicular speeds that were reflective of natural real world driving behaviour and similar SSQ scores to control. These results support the theory that cutaneous stimulation of the neck is a worthy alternative to vestibular stimulation for reducing SAS especially in scenarios requiring complex visual scenes; however, if naturalistic driving behaviour (of curves) is important, vestibular stimulation remains the better choice as it can reduce SAS symptoms (in virtual environments with low visual stimuli) and also promotes naturalistic driving behaviours.

INTRODUCTION

When studying driving, it is essential that testing be carried out in a safe controlled environment and this explains the appeal of driving simulators. Simulators have their drawbacks though. First, some drivers experience simulator adaptation syndrome (SAS), a condition which may result in nausea, disorientation, dizziness, headache, and/or difficulty focusing when in a simulator (especially fixed base simulators). Simulator adaptation syndrome has an aetiology that is still not fully understood. It involves a complex interaction of sensory perception, cognition and motor control (Stanney, Mourant, & Kennady 1998; Riccio & Stoffregen, 1991). The importance of SAS in driving research is that it limits the populations that can be studied in a simulator environment and potentially leads to critical data loss and population biases (Stanney et al., 1998). Second, because driving simulators cannot fully mimic the dynamics of an actual vehicle in motion, there is the danger that simulated driving behaviour is not an accurate representation of driving performance in a real vehicle. For example, there are no vestibular cues in fixed base simulators and Reymond, Kemeny, Droulez and Berthoz (2001), found that drivers underestimate vehicle speed when vestibular cues are absent. In real world driving the vestibular system provides information needed for the estimation and adjustment of vehicular speed when entering and negotiating a curve, ensuring adequate control of the vehicle (Reymond et al., 2001). However, when drivers negotiate curves in absence of vestibular motion cues, they do not reduce their speed appropriately, resulting in reduced vehicular control (Reymond et al., 2001).

In an attempt to address these issues, Reed-Jones, Reed-Jones, Trick, & Vallis (2007), showed that in a fixed based simulator galvanic vestibular stimulation reduced the incidence of SAS and improved steering control. Galvanic vestibular stimulation is the direct stimulation of the VIIIth cranial nerve afferent providing a vestibular perception of rotational acceleration of approximately $2°/s^2$ (Fitzpatrick & Day, 2004). This application of vestibular stimulation was hypothesized to be effective as it reduced the conflict between the visual perception of self motion, induced by the virtual environment, conflicting with the perception of a static situation from the vestibular system (Flanagan, May & Dobie, 2004). However in that work, vestibular stimulation only reduced SAS when there were no visual cues to assess speed, as occurs when there is as a blank landscape beside the simulated road. When there were clear visual cues, such as high visual clutter along a simulated roadside, vestibular stimulation actually increased oculomotor discomfort. Consequently, in this study we investigated a method of reducing SAS that may circumvent some of these negative effects and yet produce the same positive effects as vestibular stimulation. In this case, we investigate galvanic cutaneous stimulation of the neck to mimic the perception of head movements that occur while driving around curves while avoiding the oculomotor interaction of galvanic vestibular stimulation. Electrical stimulation of the neck has been shown to contribute to spatial orientation of the body in space, specifically head on trunk position (Perennou et al., 2001). In addition, a study of postural instability following simulated driving found that cutaneous stimulation over the sternocleidomastoid muscle increases the contributions of visual information to postural control (Reed-Jones, Vallis, Reed-Jones, & Trick, 2008). These results provide evidence that cutaneous stimulation may reduce sensory conflict in a virtual driving simulator, thus increasing an individual’s belief in the visual stimuli presented.

The purpose of the current study was to evaluate the effects of this new galvanic cutaneous stimulation technique as an alternative method of reducing SAS. We hypothesised that providing galvanic cutaneous stimulation would reduce symptoms of SAS but not change driver performance during simulated curved driving compared to controls. We made this prediction for two key reasons. First, cutaneous stimulation should increase participant acceptance of the virtual motion stimuli reducing sensory conflict and in turn reducing sickness. Second, because cutaneous stimulation does not cause a perception of rotational head acceleration, and consequently an estimation of cornering speed, it should not induce adaptive changes in behaviour during curved driving. In addition, we hypothesized that by providing galvanic vestibular stimulation we would induce a sense of rotational head acceleration during curved driving. These accelerations would give participants improved speed cues facilitating appropriate reductions in speed during cornering. These reductions in speed should manifest in improved vehicular control during curves.

METHODS

Participants

Thirty participants were recruited for the study and completed screening and testing (12 males and 18 females, Ages 18-22 years). To screen for those with extremely high risk of motion sickness a general health questionnaire and motion sickness history questionnaire were administered. Participants with extremely high risk of motion sickness were excluded for ethical reasons. Once the participants were screened they were randomly assigned into one of three experimental groups. These included control (drove the simulator without intervention), galvanic vestibular stimulation (received stimulation of the vestibular nerve while negotiating curves), and galvanic cutaneous stimulation (received stimulation on the neck while negotiating curves).

Simulator Sickness Questionnaire

The simulator sickness questionnaire (SSQ) was used to evaluate SAS (Kennedy, Lane, Berbaum & Lilental, 1993). The SSQ is the current standard for evaluating SAS in simulator research. The SSQ provides scores for Oculomotor Discomfort (O), Nausea (N), Disorientation (D), and Total Sickness (T).

Simulator and Virtual Environment

A Drive Safety DS-600c fixed-base driving simulator was used virtual environment immersion. This simulator consisted of image generation computers projecting the simulation through LCD display systems onto six, seven-foot projection screens that provided a 300° wrap-around virtual environment (250° in front and 50° in the rear). A Saturn four-door sedan was contained within these screens. This car was equipped with all standard vehicle controls, augmented with audio and vibration transducers and force feedback to provide a reasonably realistic driving experience.

The virtual environment simulated driving a 20-minute route through a rural environment. The simulated road represented a paved surface with a single lane each way and no median. Each lane was 3.6 m wide with a 1.8 m hard shoulder transitioning into a 1.8 m dirt shoulder. In each of the two drives participants negotiated 8 gradual curves (4 lefts and 4 rights - randomly distributed) separated by 1000 m straight road sections. The turns were modeled as gradual 90° turns with straight 70 m lead-ins, 314 m long curves with a radius of 200 m, and straight 70 m lead-outs. Each turn included lampposts placed on the opposite side of the road to the direction of the turn in order to provide visual motion cues. In the lead-in, four posts were placed 17.5 m apart, during the curve 20 posts were placed 15 m apart, and during the lead-out four posts were placed 17.5 m apart.

Stimulation

Vestibular and cutaneous stimulation were applied using an A395 Linear Stimulus Isolator. Each participant's threshold to vestibular stimulus was assessed prior to the start of the driving trials (Bent, McFadyen, Merkley, Kennedy, & Inglis, 2000). Current output during driving trials was then adjusted to two times threshold, at a range of 0.6–1.25mA. The galvanic vestibular stimulation group received, during curves, the application of an electrical current via electrodes placed bilaterally over their mastoid process directly stimulating their eighth cranial nerve afferents. Afferent stimulation of ~ 1mA signals a rotational acceleration of $\sim 2°/s^2$ (Fitzpatrick & Day, 2004), thus reflecting dynamic inertial cues that are similar to those experienced during curved driving in the real world. The galvanic cutaneous stimulation group had bilateral electrodes positioned approximately 4 cm below the mastoid process, on the cutaneous skin over the sternocleidomastoid muscle. This technique stimulated the cutaneous stretch receptors in the neck without giving any dynamic inertial cues. Threshold values for cutaneous stimulation were determined in the same manner as vestibular thresholds (Bent et al., 2000) and adjusted to two times this threshold value during driving trials (range of 0.6–1.5mA).

Experimental procedure

In all groups participants drove through the simulation twice with a 15 min break in between. Participants were asked to drive at a constant speed of 90 km/h throughout the drives (monitored every 5 minutes) but were instructed that they should adjust their speed during curves if it felt more natural for them to do so. Participants in the galvanic vestibular stimulation and galvanic cutaneous stimulation groups drove one of these two drives with stimulation applied during the curves. This in-curve stimulation was applied when drivers reached the end of the lead-in and entered the curve. The stimulation was deactivated when the vehicle reached the end of the curve and entered the lead-out. The order of stimulation (whether received on the first or second drive) was counterbalanced across participants. After each drive, participants exited the vehicle and returned to the waiting area where they immediately completed their responses to the SSQ.

RESULTS

Data Reduction

Prior to any statistical analyses turn asymmetry, between left and right curves, was evaluated using a one-way ANOVA. No significant differences were determined between right and left turns for any of the driving variables. As a result, turn direction was collapsed for the subsequent statistical analyses.

Driving Performance Variables

Three driving variables (vehicular velocity, steering variability, and lane position) were measured to assess the differences in driving behaviour between the three experimental groups (control, galvanic vestibular stimulation, and galvanic cutaneous stimulation). For steering variability and lane position there was no significant effect of experimental group ($p > .1$). However, experimental group did have a significant effect on vehicular velocity during all three areas of the curved driving; during the lead in ($p = .002$), during the curve ($p < .001$), and during the lead out ($p = .015$). Post hoc analyses (LSD) revealed that the galvanic vestibular stimulation group had significantly lower vehicular velocities than both the control and galvanic cutaneous stimulation groups (Figure 1).

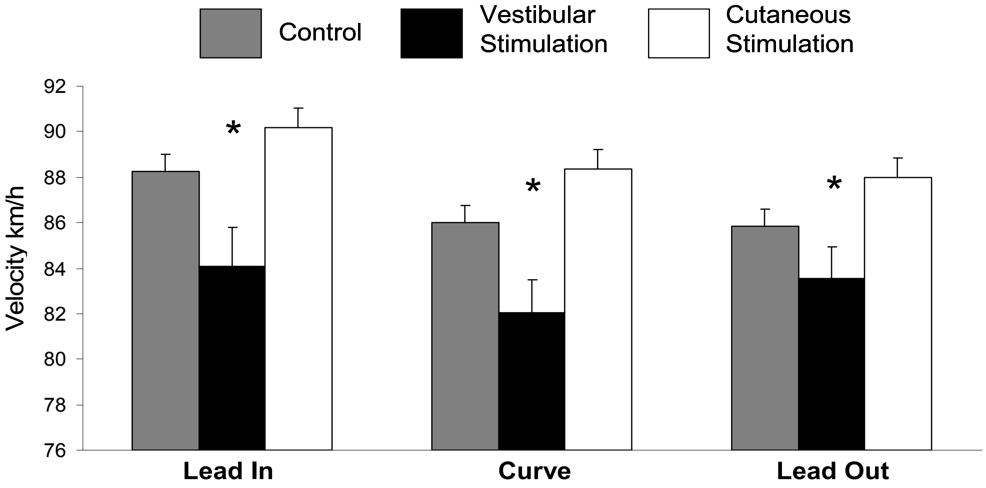

Figure 1. Mean and standard error of vehicular velocity during curve driving Asterisks (*) indicate significant differences (p<.05)

Simulator Adaptation Syndrome

To evaluate SAS, SSQ scores were analyzed using a Kruskal-Wallis test. Nonparametric analysis of the SSQ scores was used as inter-subject variability was considerable (0 - 111). No significant effect of experimental group (control, galvanic vestibular stimulation, or galvanic cutaneous stimulation) on SSQ scores was observed. However, while vestibular stimulation and control groups showed similar scores the cutaneous stimulation group showed a trend toward much lower average scores (Figure 2). It should also be noted that the vestibular stimulation group (as in our previous work) showed a pattern of discomfort more similar to what would be expected in a motion platform type simulator (O > D > N) and not what would be expected in a fixed base simulator (D > O > N) (Jaegar & Mourant, 2001).

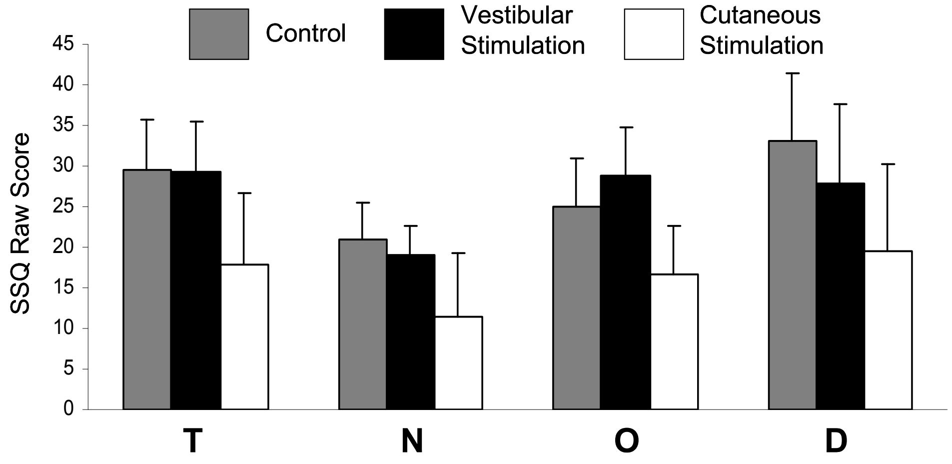

Figure 2. Mean and standard error of post drive SSQ scores Total (T), Nausea (N), Oculomotor (O), and Disorientation (D)

DISCUSSION

In a previous investigation we reported that galvanic vestibular stimulation reduced symptoms of SAS as measured by post simulation SSQ scores (Reed-Jones et al., 2007). However, during that investigation we also learned that combining vestibular stimulation with complex visual scenery actually created an interactive effect between the two sensory cues resulting in increased total and in particular oculomotor SSQ scores. It was hypothesized that the increase in oculomotor discomfort occurred because the galvanic vestibular stimulation technique induced horizontal and rotational eye responses. Combining these involuntary reflexive eye responses with the voluntary eye responses of the participants naturally fixating on visual scenery (in particular our additional lamp posts), likely created a great disturbance in oculomotor control, and subsequently increased oculomotor discomfort.

Because of these troubling findings we wanted to evaluate an alternative method of stimulation that would not evoke reflexive eye responses. In this study, the effects of galvanic cutaneous stimulation were assessed as an alternative to galvanic vestibular stimulation. Cutaneous stimulation of the neck, specifically over the sternocleidomastoid muscle, was selected as it could provide some orientation cues (via skin proprioception) of changes in head tilt during curve driving but at the same time would not elicit eye reflexes. In addition, evidence existed that cutaneous stimulation may aid in a participant's acceptance of the virtual motion stimuli (Reed-Jones et al., 2008). Based on our observation of SSQ scores, galvanic cutaneous stimulation over the sternocleidomastoid muscle does show a trend in reducing the symptoms of SAS, though the effect was not statistically significant. Unfortunately, the nature of the subjective SSQ questionnaire is that it has a high degree of inter-subject variability which affects statistical power. Despite this limitation, the reduction in scores observed in the results (Figure 2) suggests a relevant decrease in reported SAS severity.

The question thus arises as to what technique is best to use in driving simulation in order to reduce SAS. However, the answer to this question is complicated because there are many factors to consider. To begin, galvanic neck stimulation does appear to reduce SAS and may be a more effective technique than galvanic vestibular stimulation. This is particularly the case when more complex visual scenery is to be studied, for example highly built up areas or roads that have a high degree of roadside visual cues (i.e. signage, lampposts, or parked cars). However, cutaneous stimulation does not provide the same direct rotational acceleration perception that vestibular stimulation provides (Fitzgerald & Day, 2004). Cutaneous stimulation relates to a change in head position (i.e. tilt) perception (Perennou et al., 2001) and as such, the more naturalistic driving behaviour that is observed during vestibular stimulation is not observed during neck stimulation. As the results of the current study show, vestibular stimulation resulted in a significant decrease on vehicular speed on the approach to a curve, while driving a curve, and when exiting a curve (Figure 1). This reduction in speed, and the shape of the speed curve, suggests that providing vestibular stimulation reflects reductions in speed more akin to what is observed during real world curve driving (Reymond et al., 2001). The speed changes seen in the lead in and lead out (where no GVS was applied) could be a reflection of participant's anticipation of rotational acceleration (as would occur in the real world) and through this anticipation participants modified their driving behaviours accordingly. This further suggests that by providing galvanic vestibular stimulation we were successful in providing rotational acceleration cues used by the central nervous system to predict a speed safety margin for driving curves.

In summary, the findings of the current study suggest that if naturalistic curve driving is not critical to the research questions of a study then galvanic cutaneous stimulation is the better technique to use. This technique could provide for increased participant comfort and reductions in nausea and other symptoms of SAS. This could be of particular importance if a more susceptible group of individuals is the focus of study. Another advantage of this technique it that it is much easier to use in comparison to vestibular stimulation as vestibular stimulation requires very careful and specific electrode placement and stimulation threshold evaluation. In contrast, if naturalistic driving behaviour in curves is of interest and the participants are not highly susceptible to SAS then using galvanic vestibular stimulation is the better technique as it provides more realistic motion cues.

Unfortunately one of the limitations of this study was that there were no actual consequences to failures to properly reduce speed during the curves. This may have reduced the impact of the facilitation of speed estimation provided for by galvanic vestibular stimulation. A better assessment of naturalistic behaviour, for safe curve driving, would be to introduce some consequence of taking the curve too fast. For example, decreasing the friction coefficient of the road by having a wet road surface or ice or snow present would increase the risk of loss of vehicular control and perhaps increase the power of detecting loss of control of the vehicle in other driving variables (i.e. lane position and steering variability). Comparisons of vestibular and cutaneous stimulation as it relates to driving in different road conditions are currently underway in our laboratory.

ACKNOWLEDGMENTS

We would like to thank David Wilson, and Lauren Meegan. We would also like to acknowledge the financial support of the Canada Foundation for Innovation, the Ontario Innovation Trust, AUTO21 Network of Centres of Excellence, and the Ministry of Training, Colleges and Universities Ontario Graduate Scholarship (RRJ).

REFERENCES

Bent, L., McFadyen, B., Merkley, V., Kennedy, P., & Inglis, J. (2000) Magnitude effects of galvanic vestibular stimulation on the trajectory of human gait. *Neuroscience Letters, 279,* 157–160.

Fitzpatrick, R., & Day, B. (2004) Probing the human vestibular system with galvanic vestibular stimulation. *Journal Applied Physiology*, *96*, 2301-2316.

Flanagan, M., May, J., & Dobie, T. (2004) The role of vection, eye movements and postural instability in the etiology of motion sickness. *Journal of Vestibular Research, 14,* 335-346.

Jaeger, B., & Mourant, R. (2001). Comparison of simulator sickness using static and dynamic walking simulators *Proceedings from the Human Factors and Ergonomics Society 45th Annual Meeting.*

Kennedy, R., Lane, N., Berbaum, K., & Lilienthal, M. (1993) Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology*, *3*, 203-220.

MacDougall, H., Brizuela, A., & Curthoys, I. (2003) Linearity, symmetry and additivity of the human eye-movement response to maintained unilateral and bilateral surface galvanic (DC) vestibular stimulation. *Experimental Brain Research, 148*, 166-175.

Perennou, D., Leblond, C., Amblard, B., Micallef, J., Herisson, C., & Pelissier, J. (2001) Transcutaneous electric nerve stimulation reduces neglect-related postural instability after stroke. *Archives of Physical Medicine and Rehabilitation, 82,* 440-448.

Reed-Jones, R**.,** Reed-Jones, J., Trick, L., & Vallis, L. (2007) Can galvanic vestibular stimulation reduce simulator adaptation syndrome? *Proceedings of the 4th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design* Stevenson, Washington, 534-540.

Reed-Jones, R., Vallis, L., Reed-Jones, J., & Trick, L. (2008) The relationship between postural stability and virtual environment adaptation. *Neuroscience Letters, 435,* 204-209.

Reymond, G., Kemeny, A., Droulez, J., & Berthoz, A. (2001) Role of lateral acceleration in curve driving: driver model and experiments on a real vehicle and a driving simulator. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *43*, 483-495.

Riccio, G., & Stoffregen, T. (1991) An ecological theory of motion sickness and postural instability. *Ecological Psychology, 3*, 195–240.

Stanney, K., Mourant R., & Kennady R. (1998) Human factors issues in virtual environments: A review of the literature. *Presence*, *7*, 327-351.