Towards the Management and Mitigation of Motion Sickness – An Update to the Field

Joseph Smyth[1] Jonathan Robinson[1] Rebecca Burridge[1] Paul Jennings[1] and Roger Woodman[1]

[1] WMG University of Warwick, Coventry CV4 7AL, UK
j.smyth.4@warwick.ac.uk

Abstract. Almost everyone can experience motion sickness and one third of the population are highly susceptible. With growing development and popularity of technologies such as self-driving cars, simulators and virtual reality (VR), motion sickness management will be more of a consideration in the future than ever before. People who are susceptible to motion sickness may not gain the full benefits of self-driving cars (e.g., increased productivity), have access to vocations involving significant simulator-based training (e.g., airplane pilots), or have access to the increased opportunities that VR headsets may bring (e.g., vocational training or job roles involving VR). Further, with demographic variance within susceptibility to motion sickness, it is known some demographic groups are far more susceptible to motion sickness than others (e.g., females vs. males), which further identifies an inclusivity aspect to these technologies. This report evidences the strong motivation towards the mitigation of motion sickness and discusses the associated benefits. Working towards the objective of enhanced motion sickness management, this paper presents a new model to detail the onset of motion sickness syndrome and discusses the causal relationship between sensory conflict and the physiological and psychological effects of motion sickness. In doing so we identify within the existing literature many methods towards the management (both prevention and mitigation) of motion sickness and provide a direction for further study.

Keywords: Motion Sickness, Wellbeing, Treatment and Prevention, Carsickness, Nausea.

1 Introduction

Motion sickness is not a new phenomenon – humans have been documenting motion sickness as early as 800 BC [1] and there is no evidence to suggest humans have become more resilient or adept to overcome this condition today [2]. Early theories of motion sickness included that of the 'blood and guts theories', which suggested changes in flow of blood in the brain, specifically the cerebral cortex, and/or disruption to the viscera was the cause of motion sickness. These theories were eventually disproved in 1882 [3] and it was not until 1975 that we were presented with the sensory conflict theory – which we hold today as the most widely accepted theory of mo-

tion sickness. The ‘sensory conflict theory’ [4] explains that mismatches between vestibular, visual and somatosensory motion cues are responsible for motion sickness. For example, the vestibular system senses motion, yet the visual system detects none; there is a conflict between senses and motion sickness can prevail. The body’s reaction to this conflict in motion sense(s) is similar to that of a self-preservation response. Offering an explanation to this, the evolutionary hypothesis [5] proposes that when the body senses a mis-match between motion cues, the body assumes a poison has been ingested and it is that poison which is responsible for the incoherent sensory information. Thus, people often experience stomach churning, fatigue, increased sweat rate and other thermoregulatory responses as the body attempts to mitigate the effects of the suspected poison before ejecting it through the most widely known symptom of motion sickness – vomiting.

2 Background

Motion sickness affects the majority of the population, in fact it is known that everyone (besides those who are profoundly deaf) can be affected by motion sickness, and according to the U.S. National Library of Medicine, around one third of the population are highly susceptible to motion sickness [6]. It is prevalent in many domains, including in car travel (carsickness), boat travel (seasickness), in simulators (simulator sickness), in planes (airsickness) and even in virtual reality (cybersickness). Furthermore, with the growth and development in technologies such as simulation, virtual reality and automated vehicles, motion sickness is likely to become a greater problem in the future than it is today. Combining this knowledge with the evidence of the sex-effect within motion sickness opens up an interesting area for accessibility and inclusivity. Specifically, females are known to be more than twice as susceptible to motion sickness than their male counterparts as evidenced in multiple studies [7] [8] [9] and across various sectors including airsickness [10], seasickness, [11] and car sickness [12]. The implications of this identify that the many benefits and expected use cases for technology which has motion sickness as a factor are drastically more limiting for some more than others. In consideration of this, we are provided with a strong motivation to tackle motion sickness.

The issue of discomfort and aversion to certain travel methods due to motion sickness is well established and documented. As such there is clear benefit in managing motion sickness to improve comfort and wellbeing. However, we also have strong evidence to show that motion sickness affects human performance and productivity in a negative way. In industries where motion sickness is a factor (e.g., navy crew, pilot simulator training or VR training tools), this is potentially limiting to not only recruitment prospects but also job performance [13] [14] [15] [16].

Clearly there is a strong motivation to mitigate motion sickness across many sectors and this paper will summarize and discuss these efforts in the automotive domain. Motion sickness in cars (i.e., carsickness) has been a longstanding issue, although one

which is fairly easily overcome through constantly looking ahead, in the direction of travel at all times. However, with the exciting potential use cases of automated vehicles, and with occupant comfort and wellbeing giving manufactures a competitive edge, there is growing demand in this sector to tackle this area of motion comfort. In doing so we may enable car passengers today, and in future vehicles to have a better and more productive travel experience, affording opportunities other than just staring at the horizon.

3 Motion Sickness Prevention and Mitigation

In order to examine the various methods and attempts to mitigate motion sickness we must first consider the onset the condition:

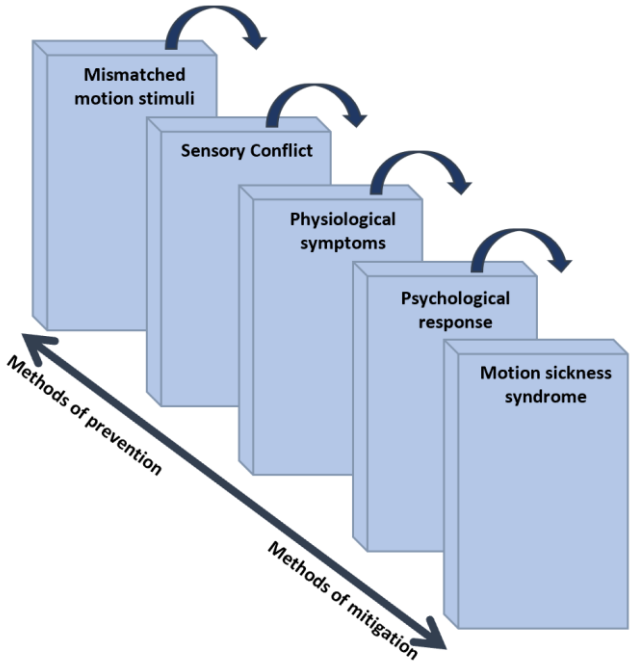

Fig. 1. Motion sickness domino model

The model presented in Fig.1 is useful for detailing the stages and causality of motion sickness onset. As was introduced previously, the first stage (the 'instigator') of motion sickness is known to be related to the presence of various motion cues that are received by the visual, vestibular or somatosensory systems. If there is a noticeable difference between these motion cues, sensory conflict [4] prevails. This leads to various physiological self-preservation responses, related to the evolutionary hypothesis [5]. The implications of this result in a thermoregulatory response [17] as well as the onset of gastrointestinal related activity [18] leading to nausea [19]. When the

human becomes conscious of the onset of motion sickness and notices these physiological symptoms (e.g., stomach churning, nausea or sweating) this manifests in a psychological stress/alarm response [20]. It is the totality of these processes that we can think about as motion sickness syndrome. The interconnected nature of these (i.e., physiological symptoms both affect, and are affected by, psychological response) is part of the reason why motion sickness is so difficult to measure objectively [20]. Further, the variance within humans, for example related to thermoregulatory ability (correlated with physical fitness) [21], and psychological perseverance and self-efficacy [22] make the actual onset of motion sickness syndrome highly variable within and between individuals [20].

Fig. 1 maps not only the onset of motion sickness, but also identifies the difference between prevention of motion sickness (i.e., stopping the onset) and mitigation of motion sickness (i.e., reducing the impact of effects). With a spectrum of opportunities for intervention identified, it becomes apparent that interventions can theoretically sit between dominoes to prevent or mitigate the onset of motion sickness. For example, highly effective suspension and vehicle dynamics to limit nauseating low frequency vibrations in a car may prevent the onset of motion sickness between the 1st and 2nd domino; or using airflow over the skin may begin to mitigate symptoms related to sweat rate and prevent or delay the psychological identification of motion sickness onset.

With the conception of motion sickness onset identified, and areas of prevention/mitigation highlighted, the literature can be reviewed to begin to understand some previous successes within the management of motion sickness (with a specific focus on carsickness). Given the range of implementation opportunities of the various methods of motion sickness management and the variety of testing environments, this paper does not seek to identify the effectiveness of specific methods, but instead work towards a greater understanding of the concepts and theories behind motion sickness mitigation strategies.

3.1 Mismatched Motion Stimuli

There have been studies investigating the provision of additional motion-related information in an attempt to prevent sensory conflict theory. Methods have been investigated involving the provision of visual cues using lights around or within interfaces [23], [24] and audio-based cues to give information about direction of travel [25], [26], [27]. Methods of haptic interventions have also been evidenced using various ‘vibrotactile’ methods to give motion cues [28] and seat vibration [29]. The degree of success of such methods are varied, but the concept remains, if accurate motion-related information can be provided (consciously or otherwise) it is conceivable that sensory conflict may not happen and thus motion sickness can be prevented.

3.2 Sensory Conflict

Still within the remit of motion sickness prevention, if it is possible to stop the brain from registering mismatched motion cues according to ‘sensory conflict theory’ then it is theoretically possible to stop the onset of physiological symptoms. Methods have been evidenced involving training visuospatial reasoning to self-resolve motions as an effective means of motion sickness prevention [30]. Other research uses bone conducting vibration (BCV) to disrupt vestibular-related motion cues in an attempt to prevent sensory conflict, which falls into this same preventative classification category [31]. Most famously the use of prescribed medication such as scopolamine [32] is an effective prevention method of motion sickness, which blocks the action of acetylcholine through disturbing vestibular communication with the brain.

3.3 Physiological Symptoms

If sensory conflict cannot be avoided, we move towards mitigation methods to limit the physiological response. Natural remedies for motion sickness mitigation often involve the use of ginger. The anti-motion sickness features of ginger are not well evidenced [33], however the ‘stomach calming’ effect of ginger is known. Ginger therefore may act as an anti-motion-sickness strategy [34] through mitigating physiological symptoms and reducing the likelihood of a psychological stress/alarm response. Other mitigation strategies may involve the treatment of motion sickness symptoms to prevent discomfort and limit psychological distress. For example, using a vehicle’s HVAC (heating, ventilation, and air conditioning) system to cool the occupant and limit sweat-related discomfort, particularly on the face [35]

3.4 Psychological Response

The role of psychology in motion sickness has been known for some time [36] and given the power of psychological some may argue it should sit above the entire ‘domino chain’ as presented in Fig.1. Where, for example, methods of increasing self-efficacy [37], distraction [38] or even relaxation through calming music [39] seem to have a positive preventative effect on motion sickness. However, it stands also as the final domino where the realization or awareness of the onset of motion sickness triggers responses linked to stress and alarm [40]. The nature of being aware of motion sickness onset exacerbates the condition [38], and we see evidence for motion sickness mitigation through cognitive-behavioral management of motion sickness [41].

3.5 Motion Sickness Syndrome

At the stage of motion sickness syndrome onset there appears to be few mitigation or prevention opportunities remaining. At this stage, the human is in a self-repeating cycle of physiological discomfort, psychological distress, and physiological responses. Avoiding the motion sickness-inducing stimulus is the only remedy at this stage, such as stopping reading a book in a car and focusing visual attention on the direction of travel.

4 Conclusive Thoughts

Motion sickness syndrome is a complex multi-factorial condition consisting of self-effecting physiological symptoms and psychological stressors. Without considerable intervention, it is likely that many of the benefits of technologies such as self-driving cars, simulators and virtual reality will not be fully achieved equally across society. We identify a significant motivation to mitigate the unwanted effects of motion sickness and introduce literature working towards this goal. This paper has presented a motion sickness domino model to detail the 'stages' of motion sickness onset and therefore providing a visual representation of prevention/mitigation opportunities with a specific focus on the automotive sector. Many methods currently discussed within the literature focus on the mitigation of motion sickness onset (e.g., treating the symptoms). However, working towards solutions for the prevention of motion sickness through specific intervention and technology design will have the greatest utility and is where future research should focus.

References

[1] D. Huppert, J. Benson and T. Brandt, "A Historical View of Motion Sickness–A Plague at Sea and on Land, Also with Military Impact," *Frontiers in Neurology,* vol. 114, no. 8, pp. 1-15, 2017.

[2] E. A. Schmidt, O. Juiper, S. Wolter, C. Diels and J. E. Bos, "An international survey on the incidence and modulating factors of carsickness," *Transportation Research Part F Traffic Psychology and Behaviour,* vol. 71, pp. 76-87, 2020.

[3] W. James, "The Sense of Dizziness in Deaf-Mutes," *American Journal of Ontology,* vol. 4, no. 4, pp. 239-254, 1882.

[4] J. T. Reason and J. J. Brand, Motion Sickness, New York: NY: Academic Press, 1975.

[5] M. Treisman, "Motion Sickness: An Evolutionary Hypothesis," *Science,* vol. 197, no. 4302, pp. 493-495, 29 July 1977.

[6] U.S. National Library of Medicine, "Motion Sickness," U.S. National Library of Medicine, Washington DC, USA, 2019.

[7] M. B. Flanagan, J. G. May and T. G. Dobie, "Sex Sifferences in Tolerance to Visually-Induced Motion Sickness," *viation, Space, and Environmental Medicine,* p. 642–646, 2005.

[8] A. Leung and K. L. Hon, "Motion sickness: an overview," *Drugs in Context,* 2019.

[9] T. Dobie, D. McBride, J. May and T. J. Dobie, "The Effects of Age and Sex on Susceptibility to Motion Sickness," *Aviation, Space, and Environmental Medicine,* vol. 72, pp. 13-20, 2001.

[10] G. Lindseth and P. D. Lindseth , "The Relationship of Diet to Airsickness," *Aviation, Space, and Environmental Medicine,* vol. 66, p. 537–541, 1995.

[11] R. Grunfeld and M. A. Gresty, "Relationship Between Motion Sickness, Migraine, and Menstruation in Crew Members of a "Round-The-World" Yacht Race.," *Brain Research Bulletin,* vol. 47, p. 433–436, 1998.

[12] M. Turner and M. J. Griffin, "Motion Sickness in Public Road Transport: Passenger

Behaviour and Susceptibility," *Ergonomics,* vol. 42, pp. 444-461, 1999.

[13] J. Smyth, P. Jennings, A. Mouzakitis and S. Birrell, "Too Sick to Drive: How Motion Sickness Severity Impacts Human Performance," in *The 21st IEEE International Conference on Intelligent Transportation Systems*, Maui, Hawaii, 2018.

[14] J. Smyth, S. Birrell, A. Mouzakitis and P. Jennings, "Motion Sickness and Human Performance – Exploring the Impact of Driving Simulator User Trials," in *9th International Conference on Applied Human Factors and Ergonomics*, Orlando Florida, USA, 2018.

[15] J. E. Bos, "How Motions Make People Sick Such That They Perform Less: A Model Based Approach," in *Symposium on Habitability of compact and transport vehicles: noise vibration and motion*, Prague, Czech Republic, 2004.

[16] J. E. Bos, P. L. Valk, M. A. Hogervorst, K. Munnoch, D. Perrault and J. L. Colwell , "TNO contribution to the Quest 303 trial - Human performance assessed by a Vigilance and Tracking Test, a Multi-Attribute Task, and by Dynamic Visual Acuity," TNO Defence, Security and Safety, Soesterberg The Netherlands, 2008.

[17] I. B. Mekjavic, M. J. Tipton, M. Gennser and O. Eiken, "Motion sickness potentiates core cooling during immersion in humans," *Journal of Physiology,* vol. 535, no. 2, pp. 619-623, 2001.

[18] W. Thornton, B. Linder, T. Moore and S. Pool , "Gastrointestinal motility in space motion sickness," *Aviation, Space, and Environmental Medicine*, vol. 58, no. 9 Pt2, pp. 16-21, 1987.

[19] J. R. Lackner, "Motion sickness: more than nausea and vomiting," *Experimental Brain Research,* vol. 232, no. 8, pp. 2493-2510, 2014.

[20] J. Smyth, S. Birrell, R. Woodman and P. Jennings, "Exploring the utility of EDA and skin temperature as individual physiological correlates of motion sickness," *Applied Ergonomics,* vol. 92, 2021.

[21] B. S. Cheung, K. E. Money and I. Jacobs, "Motion Sickness Susceptibility and Aerobic Fitness: A Longitudinal Study," *Aviation, Space, and Environmental Medicine,* March 1990.

[22] E. Dov and Z. Yaakov, "Seasickness as a Self-Fulfilling Prophecy: Raising Self-Efficacy to boost Performance at Sea," *Journal of Applied Psychology,* vol. 80, no. 5, pp. 628-635, 1995.

[23] J. Karjanto, Y. M. Nidzamuddin , C. Wang, J. Terken, F. Delbressine and M. Rauterberg, "The effect of peripheral visual feedforward system in enhancing situation awareness and mitigating motion sickness in fully automated driving," *Transportation Research Part F: Traffic Psychology and Behaviour,* 2018.

[24] Ksander N. de Winkel, P. Pretto, S. A. Nooij, I. Cohen and H. H. Bulthoff, "Efficacy of augmented visual environments for reducing sickness in autonomous vehicles," *Applied Ergonomics,* vol. 90, p. Ksander N. de Winkel, 2021.

[25] G. Galvesz-Garcia, "A comparison of techniques to mitigate Simulator Adaptation Syndrome," *Ergonomica,* vol. 58, no. 8, pp. 1365-1371, 2015.

[26] G. Galvez-Garcia, N. Aldunate, C. Bascour-Sandoval, M. Barramuno, F. Fonseca and E. Gomez-Milan, "Decreasing motion sickness by mixing different techniques," *Applied Ergonomics,* vol. 82, 2020.

[27] O. Kuiper, J. E. Bos, C. Diels and E. A. Schmidt, "Knowing what's coming: Anticipatory audio cues can mitigate motion sickness," *Applied Ergonomics,* no. 85, p. 103068, 2020.

[28] N. M. Yusof, "Comfort in Autonomous Car: Mitigating Motion Sickness by Enhancing Situation Awareness through Haptic Displays," 2018.

[29] S. D'Amour, J. E. Bos and B. Keshavarz, "The efficacy of airflow and seat vibration on reducing visually induced motion sickness," *Experimental Brain Research,* pp. 2811-2820, 2017.

[30] J. Smyth, P. Jennings, P. Benett and S. Birrell, "A novel method for reducing motion sickness susceptibility through training visuospatial ability – A two-part study," *Applied Ergonomics,* vol. 90, 2021.

[31] S. Salter, C. Diels, S. Kanarachos, C. D. Thake, P. Herriotts and D. Depireux, "Increased bone conducted vibration reduces motion sickness in automated vehicles," *International Journal of Human Factors and Ergonomics,* vol. 6, no. 4, pp. 299-318, 2020.

[32] S. A B, J. Wasiak, E. V. Villanueva and V. Bernath, "Scopolamine for preventing and treating motion sickness," *Cochrane Database Systematic Reviews,* 2004.

[33] A. Grontved, T. Brask, J. Kambskard and E. Hentzer, "Ginger Root Against Seasickness: A Conctrolled Trial on the Open Sea," *Acta Oto-Laryngologica,* vol. 105, no. 1-2, pp. 45-49, 1988 .

[34] H. C. Lien, W. M. Sun, Y. H. Chen, H. Kim, W. Hasler and C. Owyang, "Effects of Ginger on Motion Sickness and Gastric Slow-Wave Dysrhythmias Induced by Circular Vection," *Internal Medicine - Gastroenterology, Molecular and Integrative Physiology,* vol. 284, pp. 481-489, 2003.

[35] V. G. Vulcu, "Systems and methods for mitigating motion sickness in a vehicle". Southfield , MI (US) Patent US 2020/0353934 A1, 10 May` 2019.

[36] I. Zerling, "Psychological Factors in Susceptibiliy to Motion Sickenss," *The Journal of Psychology,* pp. 219-239, 1947.

[37] D. Eden and Y. Zuk, "Seasickness as a self-fulfilling prophecy: raising self-efficacy to boost performance at sea," *Journal of Applied Psychology* , vol. 80, no. 5, pp. 628-635, 1995.

[38] J. E. Bos, "Less sickness with more motion and/or mental distraction," *Journal of Vestibular Research,* vol. 25, no. 1, pp. 22-33, 2014.

[39] Keshavarz, B. and Hecht, H. (2014) 'Pleasant music as a countermeasure against visually induced motion sickness', Applied Ergonomics. Elsevier Ltd, 45(3), pp. 521–527.

[40] D. L. Harm, "Physiological of Motion Sickness Symptoms," in *Motion and Space Sickness,* Boca Raton, Florida, USA, CRC Press, 1990, p. 165.

[41] T. G. Dobie and J. G. May, "Cognitive-behavioral management of motion sickness," *Aviation, Space, and Environmental Medicine,* vol. 65, pp. 1-20, 1994.