Towards the Management of Motion Sickness for Autonomous Vehicles

WMG THE UNIVERSITY OF WARWICK

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Dr Joseph Smyth, Prof Stewart Birrell and Prof Paul Jennings

WMG at the University of Warwick.

Introduction and Problem Identification.

Humans have been documenting motion sickness as early as 800 BC [1], and there is no evidence to suggest humans are any more resilient to the condition today [2]. Motion Sickness as explained by Sensory Conflict Theory [3] is caused by mismatched motion cues received from the vestibular, visual and somatosensory systems. Almost everyone can suffer from motion sickness and one third of the population are known to be highly susceptible to it [4].

Motion sickness has been a longstanding issue in traditional travel domains including car travel (carsickness), on boats (seasickness) on light aircraft (airsickness), but with technologies such as driving/flight simulators, virtual reality headsets and more recently automated vehicles, the implications of motion sickness are far greater than ever before [5]. Automated vehicles may bring significant consumer benefits, including freeing up 'drivers' to engage in other, more productive non-driving-related tasks. Much of the public are highly incentivised by such freedoms and it is a significant motivator for the adoption of automated vehicles [6]

Morgan Stanley estimate productivity benefits of autonomous vehicles could be worth as much as US$508 billion per year to the US economy [7], with scalable benefits expected for the UK. 40% of UK train commuters already spend their commute time attending to work activities [8] which can count towards 'office hours'. There are great benefits to be had from ensuring automated vehicles can support such non-driving related activities.

However, few people today can complete work or leisure-related tasks as occupants in non-automated road vehicles. Using mobile phones, reading, working on a laptop, watching films etc. are all motion sickness inducing tasks and are commonly avoided in car travel. There is a clear mismatch between what people may be expected to do in autonomous vehicles, and what is achievable without intervention. Additional challenges are apparent when identifying the significant negative impact of motion sickness on human performance [18]. In conditionally automated vehicles this may result in a safety implication for regaining safe control of a vehicles after periods of automated driving and subsequent motion sickness onset. Further, on average, females are known to be twice as susceptible than males to motion sickness [10] [11] [12] introducing an accessibility consideration.

Our research at WMG has been working towards understanding the impact of motion sickness on human performance and in developing prevention strategies. Our most recent research project looked to overcome sensory conflict through training the ability to self-resolve motion conflicts (Figure 1) and we set out to understand:

RQ1. Can visuospatial skills be trained?

RQ2. Can we reduce motion sickness by training visuospatial ability?

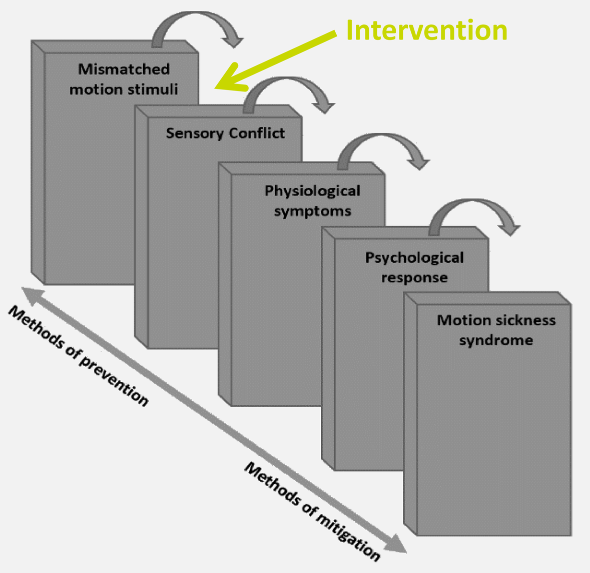

Figure 1: Motion sickness syndrome onset

Methodology.

42 participants (23 females, 19 males) were recruited across two user trials to assess the impact of visuospatial performance across two motion-sickness inducing environments containing both afferent (driving simulator) and efferent (real-world driving) motion. The methodology is detailed below, and further illustrated in Figure 2

1. Participants were assessed for their baseline visuospatial performance using a validated mental rotation test [13] (e.g., Figure 3)
2. Participants were assessed for their baseline motion sickness susceptibility using validated subjective scales both post-exposure [14] [15] and throughout the drives [16]
    - Group 1 drove for 30 minutes through a purposefully designed driving simulator route, adhering strictly to speed limits (n=20)
    - Group 2 sat in the rear passenger seat and were driven around a specific driving route for 30 minutes by a trained safety driver (n=22)
3. Experimental participants received a visuospatial training folder containing 14 pen-and-paper based visuospatial training tasks (e.g., Figure 4)
4. Participants self-trained their visuospatial skills over 14 days for 15 minutes per day. Control participants did no visuospatial training.
5. After 14 days participants returned at the same time of day and visuospatial skills were measured again
6. Participants were measured again for their motion sickness susceptibility using the same simulator (Group 1) or on-road drive (Group 2).

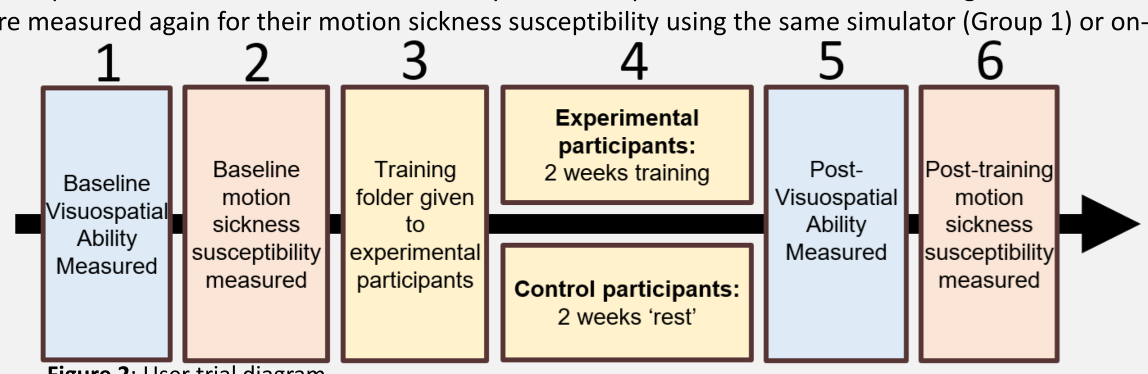

Figure 2: User trial diagram

Additional note: On-road participants (Group 2) completed a reading task throughout journeys ensure comparable behaviour between the two exposures. The NASA Task Load Index (TLX) was used to measure perceived workload for the reading task.

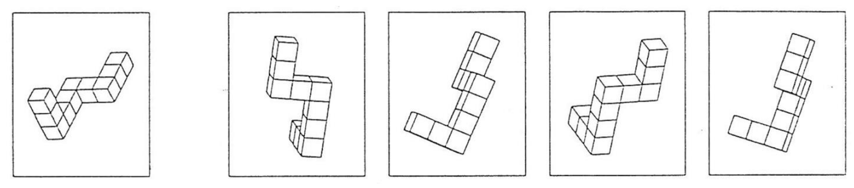

Figure 3: Mental Rotation Test (MRT) example [13]

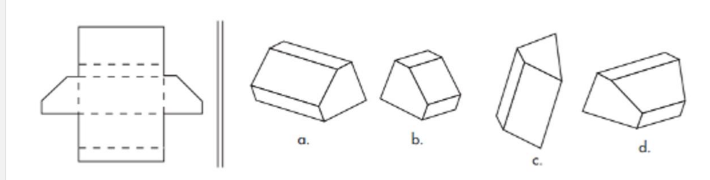

Figure 4: Understanding Patterns Test example [17]

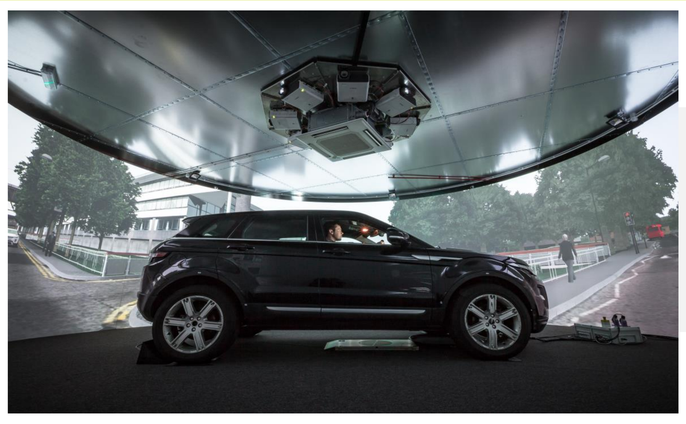

Figure 5: Group 1 3xD driving simulator study

Figure 6: Group 1 3xD driving simulator study (participant view)

Figure 7: Group 2 on-road study (participant in rear seat)

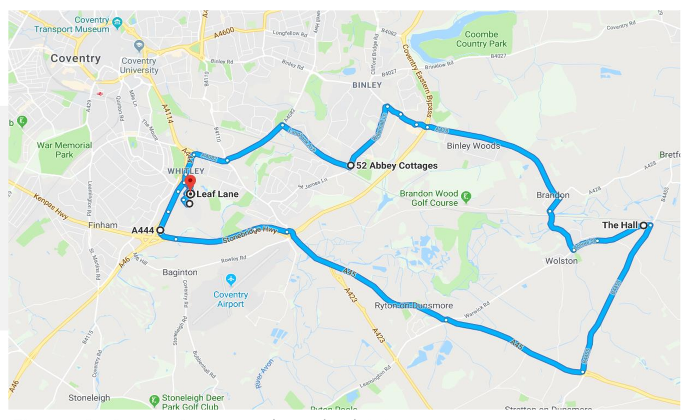

Figure 8: Group 2 on-road study driving route

Results.

Firstly, we looked to understand the effectiveness of the visuospatial training period for both groups of participants and the effect of not training for our control group as part of the on-road trial. It was found:

- The training pack improved visuospatial ability by 38.24% for Group 1 $t(19) = -4.278$, $p < 0.0001$.
- The training pack improved visuospatial ability by 45.81% for Group 2 $t(14) = -5.150$, $p < 0.001$.
- For the control group in Group 2 (i.e., those who received no visuospatial training), no change was observed $t(6) = -1.89$, $p = 0.108$

Next, we looked at the difference in subjective motion sickness scores using the Simulation Sickness Questionnaire (SSQ) [14], the Motion Sickness Assessment Questionnaire (MSAQ) [15] and the Fast Motion Sickness Scale (FMS) [16]. The SSQ scores are presented below in Figures 9, 10 and 11

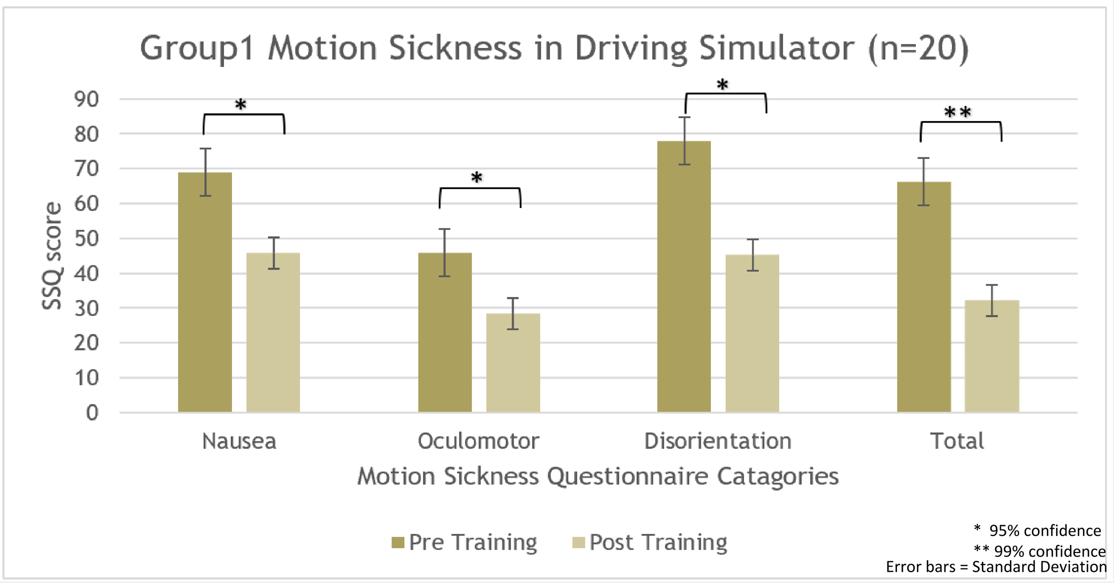

Figure 9: SSQ Motion Sickness Group 1 (simulator study)

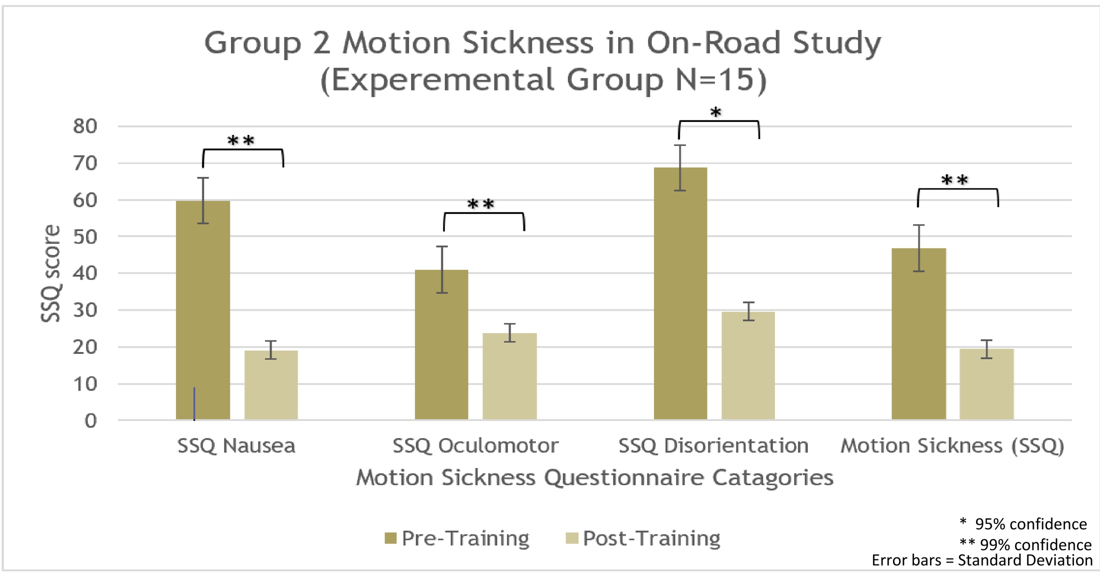

Figure 10: SSQ Motion Sickness Group 2 (on road, experimental group)

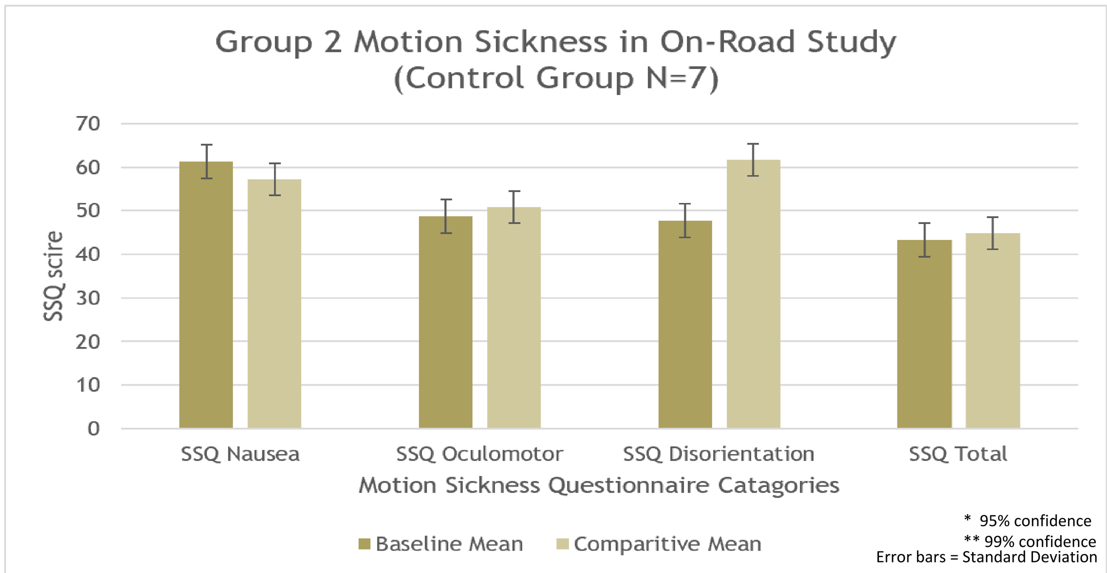

Figure 11: SSQ Motion Sickness Group 2 (on road, control group)

Table 1: Statistical analysis of SSQ scores

SSQ Category (pre training vs. post training)	df	t	Sig. (2-tailed)	% change
Nausea	19	2.175	0.043	-40%
Oculomotor	19	2.597	0.018	-46%
Disorientation	19	3.236	0.004	-53%
Total Motion Sickness Score	**19**	**4.903**	**0.000**	**-51%**

Table 2: Statistical analysis of SSQ scores

SSQ Category (pre training vs. post training)	df	t	Sig. (2-tailed)	% change
Nausea	14	5.924	0.000	-68%
Oculomotor	14	3.956	0.001	-42%
Disorientation	14	2.866	0.012	-57%
Total Motion Sickness Score	**14**	**5.456**	**0.000**	**-58%**

Table 3: Statistical analysis of SSQ scores

SSQ Category (pre training vs. post training)	df	t	Sig. (2-tailed)	% change
Nausea	6	0.750	0.482	+7%
Oculomotor	6	-0.603	0.569	+4%
Disorientation	6	-1.871	0.111	+29%
Total Motion Sickness Score	**6**	**-0.549**	**0.603**	**+4%**

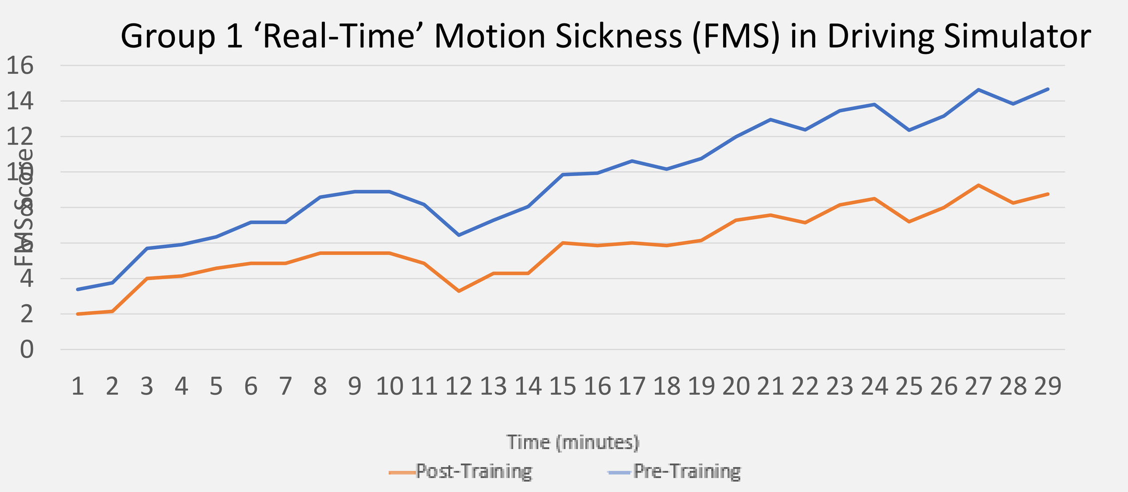

Figure 12: FMS Motion Sickness Group 1 (Simulator)

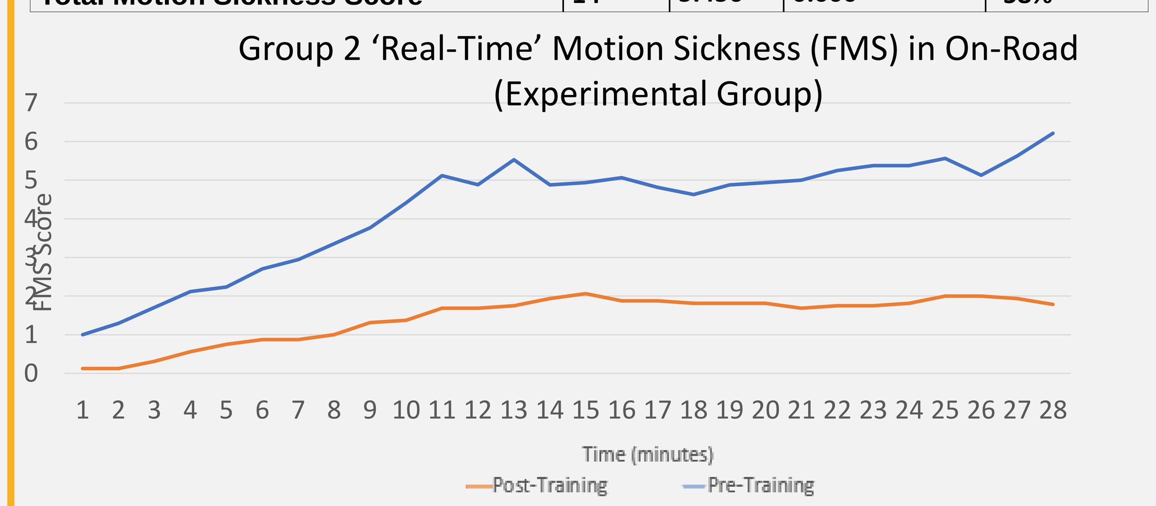

Figure 13: FMS Motion Sickness Group 2 (on road, experimental group)

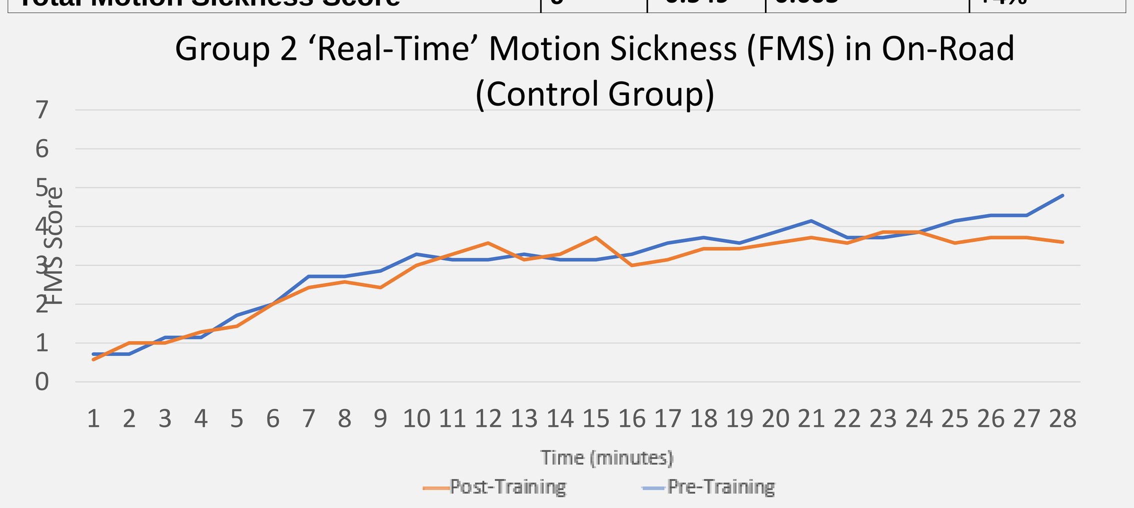

Figure 13: FMS Motion Sickness Group 2 (on road, control group)

Further findings:

- In Group 1, visuospatial training reduced dropouts due to severe simulator sickness by 46.2% $t(19)=-2.854$, $p=0.010$
- The effect of visuospatial training on motion sickness was equally as effective for males as it was females with no sex effect observed ($F=4.211$, $p=0.055$)
- In Group 2, reducing motion sickness also reduced mental workload for the reading task by 27.8% for the experimental group $t(14)2.847$, $p<0.05$, with no change observed for the control group $t(6)$-0.961, $p=0.374$

Conclusions.

This research has identified, for the first time, a causal relationship between visuospatial skills and motion sickness susceptibility. It has also demonstrated a method through which visuospatial abilities can be trained and motion sickness reduced as result. This is a novel finding and presents a new non-invasive, non drug-related and non habituation dependent method of managing personal susceptibility to motion sickness. In this first iteration of development, motion sickness was reduced by 51% in a driving simulator and by 58% in the real-world study. The implications for this work are potentially great and represent a significant step forward in the pursuit to resolve the issue of motion sickness which has been impacting humans for many hundred of years.

Such a discovery can change the way in which people can work, travel and find leisure in the future and bring us another step closer to being able to gain the full benefits that future automated vehicles are able to bring.

The two-part research methodology explored motion sickness in simulators (afferent motion) and real-world environments (efferent motion) and therefore evidences transferability of results to other domains. There is potential for benefit in other sectors for which motion sickness is a factor, such as for sea-going naval crew (seasickness) or aeroplane pilots (who require significant flight simulator training). Further, with these vocations in which motion sickness is a common factor, this finding can improve accessibility for those who suffer from motion sickness (disproportionally females). It is hoped that this research finding, and other outputs of ongoing projects will continue to develop methods of managing motion sickness, ensuring benefits of future technology including automated vehicles can be fully achieved by all.

Next Steps.

This research represents the first time such a method has been explored and evidenced, and there is strong reason to believe improvements can be made to training efficiency and overall effectiveness through further research. The progress of this research is best considered with regards to Technology Readiness Levels (TRL's). The current method sits at TRL Level 5, with validation in a relevant environment. Future research questions are found within areas for development across the breath of the TRL stages (both higher and lower), and basing research questions on this scale will help to develop our understand of this effect, and applicability for future use:

Psychophysiology of visuospatial processing skills	Psychology of training and engagement effectiveness	Specific visuospatial skills; mental rotation, spatial perception, spatial visualisation	Effects of specific visuospatial skills and training regimes on motion sickness	Effect of method in different environments/ applications	Long-term impact	Consumer acceptance for training regimes/tools

TRL 1 → TRL 2 → TRL 3 → TRL 4 → TRL 5 → TRL 6 → TRL 7 → TRL 8 → TRL 9

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