Too Sick to Drive: How Motion Sickness Severity Impacts Human Performance

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***Abstract*— There are multiple concerns surrounding the development and rollout of self-driving cars. One issue has largely gone unnoticed - the adverse effects of motion sickness as induced by self-driving cars. The literature suggests conditionally, highly and fully autonomous vehicles will increase the onset likelihood and severity of motion sickness. Previous research has shown motion sickness can have a significant negative impact on human performance. This paper uses a simulator study design with 51 participants to assess if the scale of motion sickness is a predictor of human performance degradation. This paper finds little proof that subjective motion sickness severity is an effective indicator of the scale of human performance degradation. The performance change of participants with lower subjective motion sickness is mostly statistically indistinguishable from those with higher subjective sickness. Conclusively, those with even acute motion sickness may be just as affected as those with higher sickness, considering human performance. Building on these results, it could indicate motion sickness should be a consideration for understanding user ability to regain control of a self-driving vehicle, even if not feeling subjectively unwell. Effectiveness of subjective scoring is discussed and future research is proposed to help ensure the successful rollout of self-driving vehicles.**

I. Introduction

The independent consultancy – KPMG estimate that "all vehicles produced in the UK by 2027 will have at least L3 technologies" [1], where L3 refers to Level 3 conditional automation [2]. Automakers have made significant steps towards such goals in recent years, but there are still many factors as yet unknown and in need of further development if the rollout of such technology can be realised. Further to the amass of technical and legislative barriers for self-driving and autonomy, there are still a multitude of human factors concerns in relation to the use of self-driving vehicles, from mode confusion at points of hand over to user interface design. This paper however looks at another important issue - that of motion sickness (MS) as a result of 'users' travelling in a self-driving car.

MS is commonly understood to be a comfort issue for self-driving vehicles, and rightly so. However, this paper will explore an as-yet unconsidered area of human performance. Levels 3 and 4 autonomy (in accordance to SAE guidelines [2]) dictate the need for a substantial human consideration. Where in level 3, or 'conditional driving automation', the driver may be expected to take back control of the vehicle at any time and level 4, 'high driving automation', will also allow the driver to take control of the vehicle (although it is not a requirement). Considering autonomy states such as conditional and high automation there is an even greater need for resolving human factors issues prior to a successful roll out of self-driving vehicles. One such area of concern is the vehicle handover point (i.e., where the user is expected to relinquish control of the vehicle to the self-driving system, or regain control after a period of automated driving, aka takeover). Much research has been conducted assessing various issues concerned with vehicle handover, with particular focus on areas such as "the situational awareness level of the driver and the vehicle, the knowledge the vehicle must have of the driver's driving skills as well as the in-vehicle context" [3]. One considerable issue, however, has gone largely unnoticed – the physical, cognitive and visual capacity of a driver if a self-driving car does indeed induce motion sickness.

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Considering MS, it is understood that "around 60% of the population has experienced some nausea from car travel, whereas about a third has vomited in cars before the age of 12" [4]. Aside from vomiting, MS "is typically preceded by signs and symptoms such as nausea, headache, fatigue, and drowsiness which may linger on for hours" [4]. Other than the obvious concern for passenger comfort, MS has been a fairly insignificant factor in the development of traditional vehicles mainly because of the low likelihood of drivers becoming motion sick. However, when considering self-driving vehicles (particularly levels 3 and 4 and 5 automated vehicles) the consideration of MS is of much greater importance. It is expected that self-driving vehicles are likely to significantly increase MS onset frequency and severity as drivers become 'passengers' and as people engage in other non-driving related activities such as reading or working [5]. Outside of the automotive domain, research has touched on the relationship between MS and task completion ability in users, although most studies have been industry specific and use non-transferable measurements (of both human performance and MS). Previous work conducted by the authors [6] has shown how MS does indeed negatively affect cognitive, physical, physical-visual and physical-cognitive performance, although the scale of this impact is unknown. It is speculated that the impact of such MS on human performance could affect the ability of users to regain control of a vehicle or make appropriate context based decisions - as is required in conditional driving automation (level 3), and as is possible in high driving automation (level 4). Ensuring the human is in a fit state to drive must be a key element of the human-machine interaction involved in the development of self-driving vehicles. This paper therefore aims to address the current state of research in this subject area and with independently collected data, it will look to understand the scale of the extent to which MS can affect human performance.

II. Motion Sickness – What Is It

Motion sickness (MS) is an umbrella term for a variety of motion (or perceived motion) induced 'sickness' which covers things such as seasickness, carsickness, visually induced MS (VIMS), simulation sickness etc. It is important to note that when a person is reported to be experiencing 'motion sick', at the low end of the scale they may not even be feeling 'sick' at all. For example, reports of increased salivation and fatigue may indicate a MS score, although few people would actually consider themselves 'sick', or even uncomfortable. However, in the more advanced stages of MS the symptoms can be very uncomfortable and indeed result in being physically sick. The most accepted theory to explain the cause of MS is the Sensory Conflict Theory. The theory explains that "mismatches between (or within) the visual, vestibular, and somatosensory inputs" cause MS [7]. This essentially means that if movement is sensed for example, within the inner ear, which does not correlate to the motion that is seen by the eye, then there is a conflict of senses and MS prevails. This conflict can arise if the human eye sees movement around it, but the inner ear senses no motion, or vice-versa. MS through sensory conflict can also arise through more acute mismatches, such as if the eye sees lots of movement, but the vestibular system senses only slight.

The theory of Postural Instability is also considered to be related to motion sickness. The central hypothesis of postural instability theory is that MS is caused by loss of postural control [8]. More recent studies have shown postural instability may not necessarily cause MS, but does precede subjective MS symptoms [9].

III. Motion Sickness in Self-Driving Vehicles

With the knowledge of these two theories of MS it is possible to see why self-driving vehicles may pose more of a problem for MS onset likelihood and severity than conventional vehicles. One very useful paper in this field, lists three areas that contribute to self-driving vehicle MS: "Changing roles: From driver to passenger, Engagement in non-driving activities and flexible seating arrangements" [5]. As such, when people switch between being an active driver to a passive occupant (or passenger) many things change, including the freedom to engage in other activities. Firstly, where a driver is traditionally looking at the road and inputting movement controls through the steering wheel and pedals, they are fully aware of the movement they are immediately subjected to and any future movement too. In line with the postural instability theory, a traditional driver can predict upcoming motion and scan the road ahead. However, when the person becomes a 'passenger' they are unaware of the future motions as they are not inputting motion controls. Therefore, it is harder to predict future motion and cognate current accelerations – here MS may prevail.

Considering sensory conflict theory, a traditional driver will sense movement within their inner ear which will correlate to the movement observed through their eyes as they see the road, so there is no sensory conflict when driving. However, if reading a book, or engaging in other non-driving related activities as levels 3, 4 and 5 automated vehicles may allow, the majority of the field of vision is static although movement is still detected by the inner ear. In this second instance, it is possible that sensory conflict and MS will prevail.

Considering self-driving cars, it has been theorised that "all envisaged use cases can be predicted to increase the risk of motion sickness" [10]. One paper looking at MS likelihood of adults riding as passengers in self-driving cars found that, 37% of Americans, 40% of Chinese, 53% of Indian people would "experience an increase in the frequency and severity of motion sickness" [11]. However, they also added that the "actual frequency and severity of motion sickness in self-driving vehicles might be greater than calculated" mainly due to the variation in activities passengers could engage in, and potential design changes in such vehicles (which include variability in ride dynamics which affect low frequency vibration – another effector of MS). Things are worsened further when flexible seating is considered – where "numerous concepts for autonomous vehicles suggest flexible interior layouts which frequently involve swivelling chairs allowing the driver and front passenger to turn to the rear passengers" [5].

A survey conducted by StateFarm in 2016 [12] looked to understand what people want to do within a self-driving car, given the premise that self-driving technology would free up their time to engage in other activities. They reported 45% of people would be more willing to read texts, 36% would be more willing to access the internet, 21% would be more willing to watch movies and 19% would be more willing to read a book – all tasks expected to increase MS onset/severity. Further, Morgan Stanley go on to estimate 'productivity gains would come to $507 billion annually in the US' [13] through the introduction of self-driving cars. Pointing to the expectation that users will want, or perhaps even be expected to, engage in work-related tasks which are known to increase MS. Considering also saleability of these vehicles, the literature has shown MS susceptibility can vary between age groups, genders and ethnicities (amongst other factors) [14] [15]. Modern automakers have a diverse customer base with different cars targeted at different demographics. There is therefore, a high chance some customers will be much more susceptible than others, making it critical that MS is accounted for across the entire demographic so that groups are not excluded or inadvertently 'designed out' of ownership. This concern falls within the inclusive design requirements that automakers are expected to follow. Conclusively, considering only activities occupants can engage in, a conservative 12% of American adults, 13% of Chinese adults and 17% of Indian adults would experience moderate or severe MS [11] and as such, there is a pressing need for further research to understand the impact.

IV. Motion Sickness and Human Performance

Considering cognitive task performance, one study found 5% of their users did not complete a task when not feeling 'sick at all', however "this increased to about 60%" when seasick [16] where the task was a job-related assessment. Researchers also found “a highly significant effect of seasickness on acuities” [17] where visual acuity is the ability to visually perceive detail. Colwell et al. [18] showed how cognitive task performance decreased with increased MS. A 2005 NASA sponsored project found that it is possible to increase task completion ability significantly by reducing MS [19] - although the exact effect was not quantified. A US military project advised that if a person reports MS whilst using their tank simulator they “should not be required to drive any (real-world) vehicle” [20] on account of their expected decreased task performance ability. Research projects using driving/flying simulators often recommend people should not be expected to drive a real world vehicle immediately after the study because it is believed MS “can affect performance after the simulator experience” [21]. This is based on the findings that use of virtual environments “could directly affect visuo-motor coordination” [22].

Despite these findings, the effect of MS on automotive-based task completion is a relatively under-researched area where the papers previously discussed are not directly transferable few reasons. Most importantly, none of the task completion tests sufficiently covers the breadth of task completion requirements a driver is expected to perform, where all of the ‘performance’ scoring had been in relation to job/task specific assessments. Secondly, the scale of the impact is rarely considered where the severity of motion sickness has not been correlated to the scale of human performance impact. Task requirements for driving a car include cognitive, visual and physical abilities. Where cognitive function is required for mental abilities in processing demands, route planning, appraising danger etc. Visual ability is required to identify targets, scan the road, read signs/directions and identify dangers etc. And physical tasks are related to the ability to manually control a vehicle/ system interface through dexterous interaction, motor coordination, interaction with controls etc. A breakdown of task completion abilities drivers need is presented below in Fig. 1 where the intersections between tasks are also of importance. Auditory ability has been omitted as the ability to hear is not required for driving.

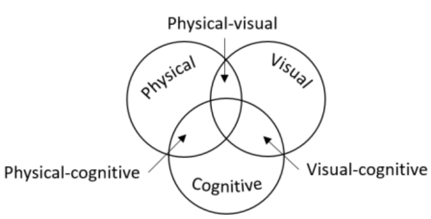

Fig. 1. Human performance areas for driving

Using this breakdown of human performance, previous research by the authors showed that motion sickness (as induced by a simulator) significantly negativly affects cognitive, physical, physical-visual and physical-cognitive performance [6], although measurments of visual and visual-cognitive performance were somewhat flawed in the study design, so remain inconclusive. Overall, this previous reserch showed there was an impact performance due to MS, where this current paper now aims to determine if more severe MS leads to increased decrement in performance (and vice-versa). Another important unanswered question.

V. Method

To assess how MS affects every possible driving related task is not possible. Instead, the human performance diagram (Fig. 1) was created so any possible driving task can be mapped to the diagram. E.g., route-planning falls within the cognitive performance section, pressing a button (requiring visual skill and physical dexterity) would fit in the physical-visual section, and interacting with an out-of-sign control may rely on just physical performance. Six assessments were chosen based on a few criteria: they should be pre-validated and standardized tests, they should each take less than 1 minute to complete, they should have no learning affect (i.e., once familiar with the test, repeated exposures should not affect the scores) and they should represent the section assigned - remaining independent of the others as much as practically possible. This methodology was used in previously published research by the same authors [6]. The pre-validated tests chosen included:

Test 1 - Visual performance: A visual acuity ETDRS LogMar test chart was used. Participants used their dominant eye, standing at a set distance and were scored on the total number of letters read.

Test 2 - Physical performance: ‘Card turning’ from the ‘Jebson Taylor Hand Function Test’ [23] was used. 3”x5” white index cards used were used on a dark table to reduce the impact of visual ability. The time taken to turn all five cards using their dominant and non-dominant hand served as the score.

Test 3 - Cognitive performance: A ‘Paced Visual Serial Addition Test’ (PVSAT) was used - a visual version of an N-Back test. See [24]) for N-Back. A laptop was used to present numbers and participants had to add the current number to the previously shown number and give the answer verbally. Numbers were presented in black text with 200pt font size on a white background to reduce any effect of visual performance (20 numbers were shown for 1 second with a gap of 2 seconds). The total number of correct answers gave the participants score.

Test 4 – Visual-cognitive performance: A mental rotation test was used [25] where a 3D shape was presented on paper alongside four other shapes, the task was to identify which two shapes matched the target shape, despite being rotated. Participants were scored on the number of complete answers of which there were 8, giving a maximum score of 4 .

Test 5 - Physical-visual performance: The Perdue Pegboard [26] was used . Participants tested with their dominant and non-dominant hand independently and were scored on the number of pins they located in the holes in the given time (60 seconds).

Test 6 – Physical-cognitive performance: A reaction time test was used where a large traffic light was displayed on a laptop screen, when the bottom green light illuminated (randomly between 1 and 6 seconds) participants pressed a physical button. This test relied on cognitive processing speed and physical response. Participants were timed for five repetitions and score was derived from the average.

For the MS 'stimulus' a route was designed for the 3xD Vehicle Simulator at the University of Warwick [27]. A simulator was used as it offers controllability over external variables, and, most importantly ensures participant safety as the effects of MS were unknown. All participants were made aware of any risks, were welcomed to end the trial at any time and were monitored throughout. When participants arrived, they completed the Simulation Sickness Questionnaire (SSQ) [28] to identify pre-existing conditions. They were introduced to all six performance tasks and ran through each as a training activity. The six tests were given again in a random order and baseline scores were recorded. Participants were then introduced to the driving simulator and drove along the pre-planned route for up to 30-minutes (including 5-minutes of familiarization) along a mixture of country, rural and motorway roads. The participant and researcher were in constant communication to monitor wellbeing, where scores were taken every minute to rate their MS as per the Fast Motion Sickness or 'FMS' scale [29]. After the driving, participants completed the six tests again (in a random order) and completed another SSQ. MS was likely to wear off after simulator use (although a precise subjective recovery time is argued), so tests were given within the first six minutes of the driving ending. Data from this paper will be analyzed looking at delta human performance scores (i.e., the difference before and after simulator use) and compared to delta MS scores. Where the SSQ was used to infer MS state, the mechanism through which motion sickness is a result is irrelevant, where levels of SSQ score are transferable across any application, including seasickness, carsickness etc.

The aim of the study was not to induce MS, but rather expose participants to an extended situation (up to 30 minutes) where MS was possible, and measure the range of responses. When adhering to best practice guidelines the 3xD simulator does not cause excessive MS. These best practices include limiting simulator exposure to ~15 minutes, venting cool air into the cabin (as provided), completion of a familiarization run (as completed), pre-screening participants for a propensity for MS and avoiding complex junctions / higher speed sweeping bends. e were specifically interested in the effect of MS on performance, hence a longer duration of scenario (30 minutes) which in the final 10 minutes exposed participants to increasingly complex turns. A prescreening questionnaire was completed and those who indicated flagged responses were given a written and verbal warning that they might experience MS and given the opportunity to withdraw. As we are exposing people to a scenario which might increase the likelihood of MS, continuous monitoring (through FMS and visually) of the participant was completed. This study was approved through The University of Warwick BSREC (REGO-2017-2090).

VI. Results

51 participants took part with 27 males and 24 females. The minimum participant age (age was reported in groups) was 22 ± 4 years, with a maximum age of 49 ± 4 years, a mean age of 31 and a standard deviation of 10.13. An exploratory analysis for task completion and MS are presented. Where abbreviations 'Dom' refer to dominant hand, 'Non.Dom' to non-dominant hand and 'Av.Time' refers to average time.

TABLE I. DESCRIPTIVE STATISTICS

Test / Measure		Pre-Driving Mean	Pre-Driving SD	Post-Driving Mean	Post-Driving SD	Δ Mean
1(Visual)	Score	1.055	0.093	1.056	0.09	0.001
2(Physical)	Dom	3.813	0.617	4.025	0.737	0.212
	Non. Dom	4.015	0.835	4.289	0.81	0.274
3(Cognitive)	Score	18.196	1.184	17.569	1.769	-0.627
4(Visual-Cognitive)	Score	3.157	1.027	3.235	0.971	0.078
	Time	79.821	43.789	74.878	43.738	-4.943
5(Physical-Visual)	Dom	16.039	1.673	15.529	1.641	-0.51
	Non. Dom	14.765	1.531	14.471	1.419	-0.294
6(Physical-Cognitive)	Av. Time	0.3	0.038	0.324	0.056	0.024
SSQ Total	Score	39.639	59.901	495.963	333.127	456.324
SSQ Nausea	Score	2.618	6.057	46.492	36.737	43.874
SSQ Oculomotor	Score	5.797	8.246	33.441	21.662	27.644
SSQ Disorientation	Score	2.183	5.113	52.678	42.797	50.495

Looking at average change in mean scores for all participants Test 1 indicated improvement, Test 2 a deterioration, Test 3 deterioration , Test 4 an improvement, Test 5 a deterioration , and Test 6 a deterioration . Regarding the analysis of performance on MS severity , participants were split into three equal groups of 17 participants, based on individual MS severity where group 1 contained participants with the lowest Δ(delta) MS scores, group 2 consisted of the next 17 participants and group 3 consisted of the final 17 participants with the greatest Δ MS scores. An ANOVA showed a significant difference between the three groups' SSQ scores ($F=81.272$, $p<0.001$)

TABLE II. DESCRIPTIVE STATISTICS OF GROUPS

Group	Mean	Standard Deviation	Standard Error
1 (n=17)	137.133	106.702	25.150
2 (n=17)	416.925	86.745	21.686
3 (n=17)	831.369	222.294	53.914

Change in performance (Δ performance) is mapped against the change in Total SSQ score averages for the three severity groups (Group 1 contains those with the lowest MS scores and Group 3 contains those with the highest). And presented in Fig. 2,3,4,5,6 and 7 below:

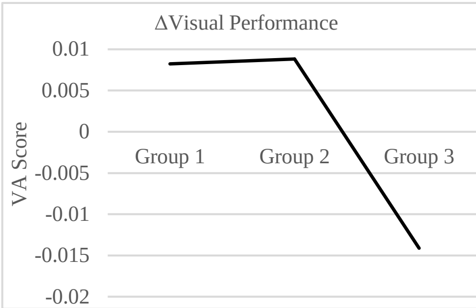

Fig. 2. Change in visual performance across three MS groups.

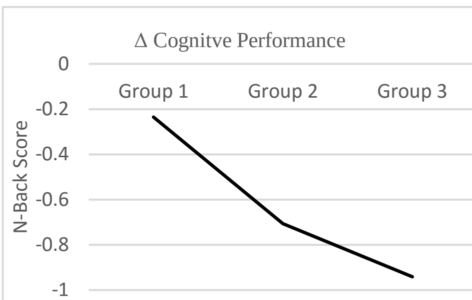

Fig. 3. Change in cognitive performance across three MS groups.

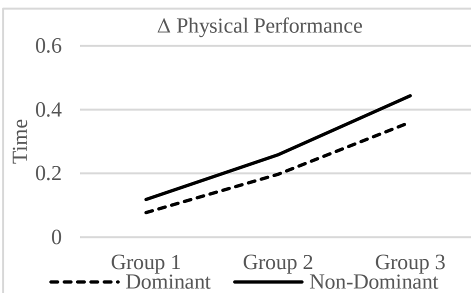

Fig. 4. Change in physical performance across three MS groups.

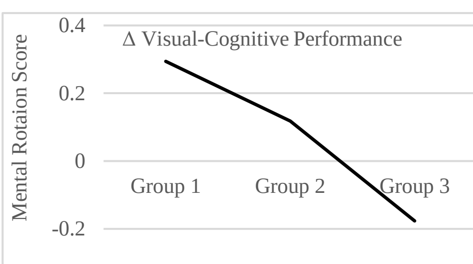

Fig. 5. Change in visual-cognitive performance across three MS groups.

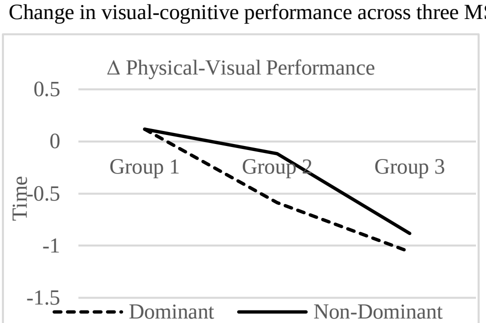

Fig. 6. Change in physical-visual performance across three MS groups.

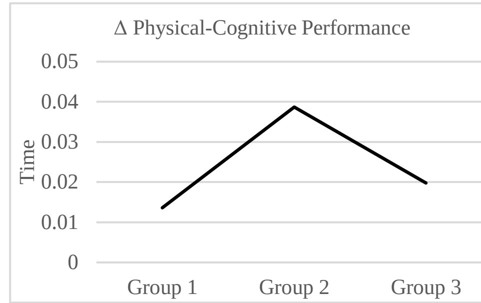

Fig. 7. Change in physical-cognitive performance across three MS groups.

Using a Levene Test for Homogeneity of Variance it was found that Test 2 (Physical) and 6 (Physical-Visual) exhibited significance where F(2,48)=4.667, p=0.014 and F(92,48)=4.255, p=0.02 respectively. The Welch ANOVA will be used for analyzing Test 2 and 6. The other four Test data sets met all assumptions so an ANOVA was used. The result of the ANOVA found no statistical significance between the three groups in Tests 1, 3, 4 or 5 where p>0.05 in all cases. Using the Welch ANOVA no statistical significance was found for Test 2 where p>0.05. However, for Test 6 (physical-visual) statistical significance was found F(2,27.168)=3.468, p=0.046. For Test 6 the Scheffe post-hoc analysis showed a statistically significant difference between group 1 and 2 (p=0.035) and group 2 and 3 (p=0.026), however there was no difference between groups 1 and 3 (p>0.05). Looking at another method for grouping the data, participants were split using total SSQ score percentiles where group 1 (25^{th}%ile) scored ≤203.21 (n=12), Group 2 (26^{th}-74^{th}%ile) scored between 203.21 and 606.965 (n=18) and group 3 (75^{th}%ile) scored ≥606.965 (n=21). No statistical significance between MS severity groups and change in performance was found in any group where p>0.05 in all cases.

VII. Discussion

Previously it was shown that motion sickness (MS) had a significant effect on cognitive, physical, physical-visual and physical-cognitive performance [6]. Where the binary categorization of motion sick or not was based on participants dropping out of the study due to sickness, or being able to complete the driving. Test 1 (visual performance) was flawed due to uncontrollable lighting–highlighting the impact of luminance on acuities. Test 4 (visual-cognitive), was also somewhat flawed since the interesting finding that the mental rotation test used is affected by simulator use regardless of MS [6]. Hence, the relationship between MS and Test 1 (visual) and 4 (visual-cognitive) is inconclusive.

Looking at the six graphs presented in this study (Fig. 2-7), there was a visual indication that this MS effect may be scalable whereby those with higher MS may have a greater impact than those who have lower MS. However, the statistics do not bear this out, hence there is very little reason to believe that an increased SSQ score (subjective MS) has an effect on the scale of change in task performance ability.

Although one significant result was found in Test 6 (physical-visual) although with only two of the three groups being different there isn't enough data to point to a scale effect, where a minimum of three points is needed to indicate a trend. Further, it is interesting to see how the lowest MS group (1) and the highest MS group (3) were no different, further supporting that MS severity had no scale of impact on performance. The findings from this analysis reveals the scale of the effect of MS on human performance varies greatly between participants, where the range of performance effects are largely independent of SSQ total score severity based on our methods of grouping. This means that it is, at this time, impossible to predict if someone with lower subjective MS will exhibit a greater or lesser change in their task performance ability than someone with higher subjective MS.

The results presented are limited by participants' ability to accurately rate subjective MS score using the SSQ. This is perhaps a limitation of the field in general whereby the subjective scale of the SSQ and other MS questionnaires may not be accurate and/or precise enough to really grasp true MS state. Although, at this time there are no widely accepted subjective or physiological alternatives available. A secondary limitation which may have affected results is the method(s) used to group participants. To date, no one has made a successful method of categorizing the SSQ in terms of severity groups. One paper [30] attempted a method although the groups overlapped and the scale used was based on a maximum SSQ score of "~300" which is not comparable to the true SSQ maximum score (2437.9).

Given what we know about the cause(s) of MS, it is possible to speculate that the change in human performance may be better physiologically/biologically explained, rather than subjectively. Where it is possible the effect of something such as sensory conflict may affect the body in such a way that is not necessarily measurable through subjective MS (at least accurately), but is impactful on performance. It should be recognized the MS 'induced' in this study was specifically 'simulation sickness', thus the transferability to carsickness or other forms of MS cannot be commented on with this data set. It is thought feelings may to differ somewhat in scale especially between the categories of nausea, oculomotor and disorientation feelings, where in sensory conflict the stationary and moving cues are opposite in a simulator to 'real world'. However, there is little reason to believe the effect (or lack thereof) of severity of MS and impact on performance is likely to be different in other MS states.

Not much is known currently about the actual role of the occupant in a level 3-5 automated vehicle. However, considering a vehicle with level 3-4 technology - where the driver is required to retake control if necessary in level 3 (conditionally automated), and has the option to take over in level 4 (highly automated), it needs to be explored if human performance skills are affected if the 'driver' is influenced by MS, especially now it is known the scale of the effect may be independent from the scale of their subjective MS. This increases complexity of MS management within self-driving vehicles. Where previously it may be thought that only severely motion sick participants will be affected, the data presented from this user trial shows that people with varying (even low) severity of subjective MS may be affected just as much. This is an area that requires further investigation, where requiring/allowing someone to take over control of a vehicle when they are cognitively, visually or physically impaired due to the self-driving vehicle is a concern. It is not possible at this point to say whether or not results discussed in this paper, or the previous paper by the authors, are likely to impact specific driving skills, but this does highlight the need for further investigation. For example, a well cited report has previously set out recommendations for a safe vehicle handover, yet the recommendations are based on a driver with presumed normal human performance ability [31]. Within this report they advised a lead-time of 10 seconds between when a takeover request is given to the driver and when the driver should be expected to regain control of the vehicle. If, for instance, the driver was suffering from MS, even with subjectively low discomfort (and therefore their visual/cognitive/physical task performance was suffering) it needs to be understood if this will impact their ability to regain control of a vehicle within this 10 second timeframe, particularly when subjective recovery takes, for the most part, between 15-30 minutes [32]. Other sources have also recommended similar handover times of 10 seconds or less, for example, Audi's 'Traffic Jam Pilot' (level 3 conditionally automated vehicle) which will give a 10 second warning before giving back control. This highlights a significant miss-match between what is to be expected of users (10 seconds), and what may be possible by severely or acutely MS 'drivers' (15-30 minutes).

VIII. CONCLUSION

Many automotive manufactures are hoping to get cars with at least level 3 autonomy onto roads as soon as possible - KPMG predicts rollout of such technology from as early as 2020 [1] (p.7). If automakers want to meet their current targets, it will be imperative that human factors research is considered, such as that presented here and subsequent recommendations are effectively implemented in vehicles. The literature explains self-driving vehicles (levels 3-5) are expected to increase MS onset frequency and severity (an estimated 52.7% of Indian adults will likely be affected for example [11]). This, and previous [6], research has shown how such MS can also affect various areas of human performance.

The results presented in this paper show that the scale of the effect of decreased human performance is, for the most part, independent of subjective MS severity - where people with lower subjective MS are affected in a comparable way to those who have higher subjective severity. Meaning although someone may only be feeling slightly motion sick, the impact of that motion sickness on their performance many be just as severe as one with greater motion sickness feelings. The consequence of this for self-driving vehicles (which may induce motion sickness for some) needs to be seriously considered. This paper has also highlighted that perhaps subjective scoring is not an effective way of grading motion sickness severity. This paper has taken the first steps in understanding a new area of research that has yet to be fully explored. Based on the initial findings presented here there is good reason to recommend further research in: (1) exploring the ability to categorise MS severity states (subjectively or otherwise) with an aim to understand further the impact on human performance, and (2) the exact impact (if any) of MS on self-driving car specific 'driver' requirements from a competency perspective (such as vehicle handover safety).

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