Motion Sickness, Motivation, Workload and Task Performance in Automated Vehicles

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ABSTRACT

Previous literature has reported moderate losses in performance on cognitive tasks in the presence of mild motion sickness and concluded that motion sickness likely affected task motivation. These studies have used simple fundamental cognitive tasks, unlike the activities users of automated vehicles are expected to engage in. In this study we used a reading comprehension task with ecological relevance to automated driving. The study had a 2x2 within-subjects factorial design. The factors were the presence or the absence of motion and task incentive. We found no effect of motion nor incentive on task performance. We did however find a significant effect of motion sickness on subjective workload. This may mean that under more naturalistic conditions motion sickness may lead to task avoidance, which is of importance to the utility and acceptance of automated vehicles

KEYWORDS

Motion Sickness, Motivation, Task Performance, Workload

Introduction

The presence of automated vehicles on our roads is fast becoming feasible with fully automated SAE Level 5 vehicles being expected to reach 50% of market share between now and 2050 [1], [2]. Self-driving vehicles are envisioned by society as the embodiment of freedom, allowing its occupants to make use of otherwise unproductive travel time. Surveys reveal that approximately 40% of respondents would like to use this time to engage in cognitively demanding tasks such as working or reading [1]. However, a major expected impediment to performing these tasks, or indeed performing them in an optimal manner, is motion sickness.

Motion sickness is a syndrome whereby aggravating body motions trigger autonomic symptoms such as salivation, dizziness, headaches, panting, hot/cold flushes, stomach awareness, nausea and vomiting [3]. Exposure to sickening motions, such as those that may be encountered during daily traffic commutes, may in some individuals even lead to the Sopite syndrome, which is associated with lethargy, fatigue and drowsiness [4]. Indeed, it is known that around 2/3 of the population has experienced some car sickness during transport [5]. Therefore, fully quantifying the effects of motion sickness on task performance in an ecologically valid manner is an important step towards contextualising the detrimental effects of motion sickness on the adoption of automated vehicles.

Previous experiments on the effect of motion sickness on task performance reveal a small, but significant effect. One study notes a significant decrement for short term memory for the motion sick group over the not sick group -11% [6]. Another, notes a small correlation, with r = -0.21 between sickness ratings and task performance in a visual search task [7]. Likewise, [8] reported a small correlation of r = -0.15 for the case of a perception task, here an increase in the reaction time was also noted r = 0.11. Lastly, experiments on the combined effect of motion and sleep deprivation on task performance, noted a small correlation between sickness and task performance ρ = -0.19 [9]. Therefore, the consensus seems to support a small effect of motion sickness on task performance.

However, this small drop in performance may not be representative of the performance loss one might expect in more naturalistic settings. For the experiments described above, both the act of taking part in an experiment (i.e., the Hawthorne effect [10]) and the experimenter (i.e., the Observer-Expectancy effect [11]) may provide implicit motivation to the participant. This motivation may help the participant overcome the difficulties imposed by motion sickness. In [4] task performance was studied in two motion sessions. They observed a significant difference between the performance of symptomatic and asymptomatic participants, for memory and arithmetic tasks (ρ = -0.545 and ρ = -0.6 respectively), but only in the second motion session. This performance loss was attributed to the absence of implicit motivation provided by setting and task novelty. Moreover, this loss in performance was only observed for the more complex tasks of memory and arithmetic; not in simpler visual and auditory reaction tasks. It may thus be hypothesized that tasks that are complex and provide low implicit motivation are most affected by motivational losses.

Our work aims to address the following open questions: First, it is not clear how performance loss in abstract experimental tasks compares to performance loss for activities passengers may engage in when travelling in automated vehicles, such as reading and performing computer tasks. Therefore, a task that is more ecologically relevant, but still provides well defined performance criteria is needed. Second, the heave, roll and pitch motions used in the study by [4] are quite dissimilar to accelerations one would encounter when travelling in an automated vehicle. Therefore, the present study also aims to use motions that are more representative of autonomous vehicular transport. Thirdly, we directly manipulated and tested the hypothesis of an effect of motivation on motion sickness and task performance. Lastly, apart from motion sickness and motivation, task performance may affect perceived workload, and these variables may interact in complex ways. We will therefore also explore the relationship between motivation and perceived workload in the context of performing complex tasks whilst motion sick.

In this study we presented participants with a reading comprehension test derived from UKCAT verbal reasoning practice questions. The UKCAT is an exam taken by prospective medical students in the United Kingdom. The study had a 2x2 within-subjects factorial design. The factors were *motion*; where participants were either stationary or exposed to physical motions while performing the task, and *incentive*, where participants either competed for a monetary reward or not. Throughout each experimental session, participants' subjective sickness level was measured using the MISC scale [12], as well as after using the motion sickness assessment questionnaire (MSAQ) [13]. Moreover, we administered the NASA-TLX perceived workload questionnaire [14], and an adaptation of the Situational Intrinsic and Extrinsic Motivation questionnaire (SIMS) [15]. Task performance was quantified using the time-between-correct answers and accuracy of answers.

Methods

Participants

Participants were recruited amongst Bachelor and Master students of TU Delft. The limitation of the study to this demographic also meant that the incentive offered had a similar valence to each participant [16]. Efforts were also made to ensure that none of the participants knew or knew of the experimenters prior to the experiment. The recruitment was done by putting up flyers in notice boards and forwarding experiment adverts via the university intranet. The flyer stated the existence of a potential reward. Due to the stringency of the recruitment and corona restrictions only 8 participants could be recruited for this study (mean age = 26 years, STD = 2.87, 2 female, 6 male). The 8 participants had a mean motion sickness susceptibility questionnaire short form (MSSQ-Short) [17] score of 15.35 (STD = 13.72) indicating that they had above average susceptibility corresponding to the 63rd percentile.

Experimental Procedure

Participants came in to four sessions in total. All sessions were separated from each other by one week to prevent habituation effects. The experiment had four conditions evaluated in a within-subjects 2x2 full factorial design. The four conditions are; Motion-No Incentive, Motion-Incentive, No Motion-Incentive and No Motion-No Incentive.

Instructions to Participants

The participants were briefed at the start of each session. They were first told whether the session is a "graded" session with a ranking and monetary incentive or not. The monetary incentive gave 50 euros for the 1st , 30 for the 2nd and 20 for the 3rd highest scoring participants. The participants were then familiarized for a few minutes with the sickness scale to be used during the experiment. The participants were then placed in the driving simulator and asked to assume a natural posture. The seat belt was then secured around them. The participants were then given a laptop which presented to them the UKCAT verbal reasoning questions. Motion sickness ratings were queried after every other question. This was done by presenting a selectable MISC scale on the laptop screen. The questions were presented using psytoolkit [18]. The session lasted for 60 minutes, or the participant no longer wanted to continue due to motion sickness. The participants then filled out the SIMS, NASA-TLX and the MSAQ**.**

Apparatus & Motion

The experiment was performed using a driving simulator with hexapod motion platform. Bolted to the platform is the front half of a Toyota Yaris with the engine and other such components removed. The participants were seated on the passenger seat of the Yaris and belted in with the vehicles' own seat belt. During the experiment, participants wore an ear-enclosing headphone with embedded microphone which allowed for continuous two-way communication. The participants were subject to a multi-sine fore-aft and lateral accelerations, consisting of 4 sine waves at frequencies between 0.18-0.5 Hz with maximum amplitude of the final maximum acceleration value coming to 0.51 ms^{-2} for the longitudinal and 0.37 ms^{-2} for the lateral directions.

Task

As discussed in the introduction we are primarily interested in ecologically relevant tasks that can be more easily extrapolated to real work. Literature shows examples of "simulated" office work. This includes the operation of mouse and keyboard, writing, mental arithmetic but also quantitative and verbal reasoning [19]. We conducted a small pilot to determine that UKCAT was the most appropriate test for verbal reasoning for our purpose.

In our specific implementation, the task consisted of the presentation of a series of 15 written texts, with a length of approximately 200-300 words each, in one paragraph. For each paragraph, there were four multiple choice questions with three or four response categories, presented sequentially. All participants performed the task under four experimental conditions. To prevent them from answering questions on the basis of recollections from a previous session, we developed four variants of the task; one test-set for each experimental condition. The choice of test-set for a particular experimental condition was randomized between participants.

Results

For the motion conditions the mean MSAQ score for the motion condition was 34.2 (STD = 23.4) indicative of mild symptoms. Only 1 sessions out of the 16 total was cut short due to sickness. Lastly, participants obtained moderate accuracy of 64.2% in the task, exceeding pure guessing.

Evaluation of test-set difficulty

To counter confounding effects of task difficulty, we aimed to equalize the difficulty of the four test-sets used in the different experimental conditions based on pilot results. To validate this, we compared the score (#correct-#incorrect responses) and the reaction times between test-sets. There were no differences between these measures (score: F= 2.046, p=0.130; reaction time: F= 1.902, p=0.152).

Effect of Motion and Incentive

On the basis of a literature review, we formulated a series of hypotheses on the effects of motion and incentives on motion sickness ($y = MSAQ$), motivation ($y = SIMS$), workload ($y = TLX$) and task performance ($y = Score$). We evaluated these hypotheses by fitting linear mixed effects models of the following form (in Wilkinson notation):

$$y \sim motion * motivation + (1|id)$$

Here and represent effects for the factor variables described in the methods section, and the asterisk indicates fixed main effects and an interaction effect are included. The $(1|id)$ part specifies a random intercept for each individual, to account for individual differences in ability.

There was a significant effect of motion on MSAQ ($F = 5.97$, $p = 0.023$) with a coefficient of 21.9 meaning an increase in the MSAQ level of 21.9 over the baseline (intercept) value of 12.8. All other differences between means did not reach statistical significance. We note however that, the effect of motion on motivation ($p = 0.14$) with an average decrease of 4.3, leads to a drop in SIMS that is 92% of baseline, this likely to become significant with more data. Similar consideration also applies to the effect of motion on workload (p = 0.181) with an average increase of 7.3, leading to a rise that is 113% of the baseline.

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The experimental conditions do not elicit a perfect manipulation of the dependent variables. Therefore, we also computed the influence of dependent variables measuring motivation, or a lack, of in the form of amotivation (this measure was based on the scores given to 6 items in the SIMS, example of one such item is *"I do this activity but I am not sure if it is worth it"*) and motion sickness using the MSAQ with task performance and workload. These dependent variables are better representations of the manipulation we attempted to do with our experimental conditions of incentive and motion.

Evaluating only the fixed effect of MSAQ and amotivation on performance (without interaction effects) we find that the effect of MSAQ on performance was not significant ($F = 0.618$, $p = 0.437$) however the effect of amotivation on performance was significant ($F = 5.97$, $p = 0.021$) with a coefficient of 0.33 relating the amotivation scores of the SIMS to task performance.

Evaluating only the fixed effect of MSAQ and amotivation on workload (without interaction effects) we find a significant effect of MSAQ on workload ($F = 14.2$, $p < 0.001$), with a coefficient of 0.38 relating MSAQ scores to NASA-TLX subjective workload scores. This corresponds to a 15% increase in subjective workload for mild motion sickness. Lastly, we find a non-significant effect of amotivation ($F = 0.797$, $p = 0.379$) on workload.

Discussion

The insignificant finding of the effect of motion and incentive likely owes itself to the small sample size of this study. In the case of motion, it may also be because the mean sickness level reached in this study was mild. There was also between participant variability in sickness, with some participants reaching high MSAQ scores, whilst others not getting sick at all. This in turn reduced the effect of motion.

Likewise, the incentive condition did not significantly increase the score of the participants. It is likely that despite our best efforts to motivate the participants motivation was not enough or that the implicit motivation provided by the experimental setup was. It is also possible that, despite the instruction, the participants did not uniquely attribute incentive to the incentive sessions, but to the overall experiment. This is a weakness of the within participants design.

We do, however, find a significant effect of amotivation on task performance in this experiment. It is unclear from the experiment whether it was a cause or an effect of performance. Administration of the SIMS prior to the experiment may clarify this.

Lastly, there was a significant effect of motion sickness on subjective workload. This to our knowledge, is the first quantification of an intuitive phenomena. Despite this increase in subjective workload, we did not find a significant effect of sickness on performance. This is likely because, in addition to the small sample size of the study, the participants likely employed more cognitive resources to complete the given task. However, in naturalistic settings it is possible that the higher workload can encourage maladaptive coping strategies such as task avoidance [20]. Such behaviours could be studied in particular in naturalistic settings giving participants freedom in task selection and pace exposed to realistic automated vehicle motion.

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