Assessing the impact of selective attention in a minimalist virtual reality driving simulator: An analysis of perceived experience and motion sickness

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Abstract

Driving is a complex cognitive task that is prone to distractions, especially visual ones. Efficient visual selective attention is critical for safety; therefore, it is necessary to study the effects of distraction on driving. Conducting experiments on real-life driving behaviour raises serious practical and ethical concerns; therefore, we investigate the use of virtual reality in this area. In particular, we are exploring the use of low-cost virtual reality simulators using commonly available hardware and simple AI techniques to ensure easy reproducibility of our experiments.

Our study investigates techniques to improve attention in two age groups using a driving simulator. Participants' immersion and motion sickness are assessed through questionnaires. We aim to determine whether simpler setups maintain immersion and mitigate motion sickness, offering insights for the selection of future research equipment.

Keywords

driving, virtual reality, brain stimulation, IGroup Presence Questionnaire, Simulator Sickness Questionnaire

1. Introduction

Driving is a complex cognitive task influenced by various factors, including distractions. Distractions can stem from both visual and acoustic sources, with visual distractions generally having a more significant impact due to the visual nature of driving. The allocation of attention resources to multiple driving tasks is a delicate balance, which can be disrupted by distractors, such as dashboard lights, road signs or advertisements.

To enhance driving safety and prevent distraction-related accidents, efficient visual selective attention is essential [1, 2, 3]. Selective attention is linked to better driving performance, lower crash rates, and safer lane changes [4, 5, 6]. Additionally, other attentional mechanisms, such as

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divided attention and sustained attention, play crucial roles in safe driving [7, 6]. Consequently, the need to assess the impact of diverse distractors on driving performance and to devise effective attention-enhancing strategies and techniques becomes evident in the context of enhancing road safety. Unfortunately, conducting experiments of this nature presents inherent challenges. The introduction of distractors into real-world driving scenarios raises ethical concerns, as such interventions carry a substantial risk of causing serious accidents. However, recent years have witnessed an increasing interest in virtual reality (VR) environments, primarily owing to their capacity to deliver an immersive experience while avoiding the hazards inherent to real-world evaluations.

Driving simulators designed for virtual reality encompass a broad spectrum of configurations, ranging from simple setups using desktop computers equipped with a steering wheel, to highly sophisticated systems replicating car interiors with multi-axial vibration and shaking mechanisms. Additionally, the adoption of VR headsets further enhance the immersive potential of these simulators.

While there may be a natural inclination to consistently opt for the most advanced and immersive equipment, this choice carries several potential drawbacks. Foremost among these is the prohibitive cost associated with top-tier equipment, which can significantly impede widespread adoption. Reproducibility stands as an essential principle in scientific investigation, particularly within clinical research contexts. Consequently, the adoption of excessively expensive equipment should be judiciously considered, as it has the potential to compromise the reproducibility of experiments by other researchers.

The hardware used is not the only factor that influences the immersion and realism of a simulation. The software components also play a decisive role. In the context of driving simulators, besides the graphics, the behaviour of other artificial agents can also strongly influence the experience. For example, road users or pedestrians with realistic behaviour, that react realistically to the user's actions, can greatly increase the realism of a simulation. Hence, artificial intelligence (AI) techniques of various kinds, from "traditional" techniques to recent deep learning-based techniques, play a crucial role as they are used both to interpret the user's behaviour and to select the best actions for the autonomous agents.

Considering the importance of reducing the effects of distractors, we designed a study to evaluate the effect of brain stimulation techniques on driving activity. Functional imaging studies have highlighted the role of the dorsal frontoparietal attention network in managing distractions while driving [8, 9, 10, 11]. Brain stimulation techniques, such as transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS), have shown promise in improving attentional abilities and reducing the impact of distractions [12, 13]. However, the specific effects of these techniques on attentional performance in healthy adults are still being explored. In our comparative study, we investigated two distinct age groups, one comprising younger individuals and the other consisting of older participants. The assessment was conducted utilizing a driving simulator designed to replicate an highway environment. For the reasons mentioned earlier, we opted for a minimalist simulator configuration, utilizing a standard gaming setup that included a computer, a steering wheel, pedals, and a gear shift.

Following each session of the experimental procedure, participants were asked to complete questionnaires regarding their subjective experiences of immersion within the simulation and any sensations of sickness they may have encountered.

With this work we want to clarify whether a simplified simulation, akin to the one used in our study, still provides a sense of immersion and whether it effectively reduces the potential disadvantages of more immersive simulators, such as motion sickness. We believe that our findings can offer valuable insights for fellow researchers considering the optimal selection of simulation equipment for future investigations within this domain. While the main goal of the experiment was to evaluate the effects of different kinds of neuromodulation on attention while driving, in this article we focus only on the effectiveness of our simulation setup. Therefore, the research question we want to answer with this work are:

RQ1: Is our simple simulator effective in terms of realism, presence and involvement?

RQ2: Does our simple simulator produce motion sickness?

In Section 2 we describe the experimental setup, the simulation we developed, the hardware, and the simulation software we used. Section 3 introduces the questionnaires we used to evaluate presence, realism and involvement of our simulation setup and the motion sickness it produces. Finally, Section 4 discuss the results of the questionnaires.

2. Experimental setup

2.1. Participant Recruitment and Inclusion Criteria

We recruited two groups of participants of different ages. The first one is composed of 27 healthy participants, with an average age of 24.7 years (Standard Deviation, SD = 2.6), spanning an age range from 21 to 30. This group consisted of 25 right-handed individuals and 2 left-handed individuals. Recruitment occurred through the Sona System of University of Milano - Bicocca. The inclusion criteria encompassed individuals aged between 20 and 35 years, possessing a valid driving license for a minimum of two years, normal or corrected-to-normal vision, and normal hearing, as confirmed by self-reporting. Exclusion criteria entailed a history of neurological or psychiatric disorders, epileptic seizures, intracranial metallic implants, cardiac diseases, or substance abuse or dependence. These criteria align with established safety guidelines for noninvasive brain imaging techniques [14, 15, 16]

The second group is composed of 22 older individuals with a mean age of 68.7 years (Standard Deviation, SD = 2.5), spanning an age from 64 to 73 years old, with no left-handed participant. Inclusion criteria are the same of the previous group, with the exception of age, which had to be above 64 years old. Table 1 summarizes the characteristics of the two groups of participants.We wanted to make sure that the only significant difference between the two groups was age. Otherwise, other characteristics could influence the results. Therefore, we used a t-test to evaluate any statistically significant difference between the two groups. The p-value of such a test is given in Table 1. The only significant differences concern age and number of years with a driving licence. These differences are to be expected, of course, since the two groups differ in terms of age. Apart from age, we can confirm that the two groups are similar in terms of other factors that might affect attention while driving, such as sleeping time and the number of hours or kilometres driven per week.

Table 1
The characteristics of the participants to the experiment. With the exception of numerosity and the number of participants wearing glasses, we report means and standard deviations in parentheses. The column p-value indicates the p-value of a T-test used to evaluate the differences between the two groups. "n.s." stands for "Not Significant".

	Youngs	Elderly	p-value
Numerosity	27	22	<0.0001
Age	24.5 (3.1)	68.7 (2.5)	<0.0001
Years with driving license	6.3 (2.5)	49.13 (3.8)	n.s.
Use glasses	17	14	n.s.
Driving hours per week	4.5 (2.5)	5 (2.4)	n.s.
Distance per week (km)	148.6 (142.7)	103.8 (124.3)	n.s.
Usual sleeping time (h)	7.3 (0.77)	7.0 (0.9)	n.s.
Sleeping time previous night (h)	7.0 (1.2)	7.0 (0.7)	n.s.

We secured written informed consent from all participants, adhering to the principles outlined in the Declaration of Helsinki. Ethical approval was granted by the University of Milano-Bicocca Ethical Committee (605/2021; 27/04/2021).

2.2. Driving Simulation Setup

Participants had to perform a driving simulation task, which employed an adapted version of paradigms previously utilized by Karthaus et al. [17, 18].

The simulation environment hardware comprises a set of components, including a computer, three screens, a chair, driving pedals, and a steering wheel. The arrangement of these components was thoughtfully designed to emulate the field of view experienced during real-world driving, with a visual representation depicted in Figure 1. It has to be noted that our setup also captures the lateral field of view, which we consider crucial for instilling a sense of realism into the simulation. Although the main part of the simulation typically occupy the central screen area, we believe that this panoramic representation contributes significantly to the overall immersive experience.

To replicate a car's control interface, we employed standard gaming peripherals for the pedals, steering wheel, and gearshift. In keeping with simplicity and accessibility, we utilized a standard chair for seating. To enhance participants' immersion within the environment, a curtain panel was used to separate them from the supervising researcher, and ambient lighting was dimmed during the driving sessions.

Our selection of this setup followed a meticulous evaluation of various alternatives. While we acknowledge that our configuration may not match the high degree of realism offered by the most recent alternatives, it boasts crucial advantages: cost-effectiveness and ease of replication. We firmly believe that these attributes are indispensable for ensuring the protocol's reproducibility and its applicability across diverse contexts.

In terms of realism, the least realistic component within our experimental setup is the seating, consisting of a standard fixed chair. Although alternative solutions exist that mimic authentic car seats (often resembling sports car seats), our choice remains significantly more cost-effective and widely available.

Furthermore, we deliberately avoided the use of head-mounted displays, such as virtual reality visors, as an alternative to conventional screens. While these devices provide an exceptionally immersive experience, they do come with potential issues, notably motion sickness, which can afflict individuals unfamiliar with such technology. Considering that our target demographic encompasses elderly individuals, many of whom may not have prior experience with such equipment, we opted for the use of standard monitors arranged in a semi-circular configuration.

For the simulation software, we selected the well-established CarnetSoft driving simulator, a platform which have already been used in similar experiments [17, 18].

Since the final goal of our experiment was to compare the effects of the different types of tDCS, each participant took part in three driving sessions. Before each session, the participant underwent a neuromodulation session of one of the following types: conventional tDCS, Focal High Definition tDCS, or a placebo tDCS (sham treatment). In this paper, we focus on the efficacy of our simulation setup, rather than on the neuromodulatory effects. Therefore, we report results of the sham treatment only.

The simulation replicates a highway in the countryside. Within this context, users navigate a predetermined route that traverses the highway, takes an exit, and subsequently re-enters the highway. This path forms a continuous loop, repeated multiple times within a single session. Consequently, it features a diverse range of elements, including wide-radius turns, sharp bends, and nearly straight stretches. While the path is never perfectly linear, the curvature is imperceptible for extended sections.

Furthermore, the simulation incorporates vehicular traffic, consisting of cars, lorries, and

Figure 1: The simulator used for the experimental activity.

motorbikes. Given the highway setting, the are no pedestrians, bicycles, or intersecting roads. The composition and behavior of the traffic, including actions such as following or overtaking the user, are randomized. This inclusion of traffic, altough with simple dynamics, and the use of a non-straight path sets our work apart from prior experiments [17, 18], which used simpler kinds of environments.

The participant's control over the vehicle is constrained, intentionally limiting simulation variability to ensure reproducibility. Specifically, the participant's car adheres to a predetermined path, automatically maintaining a constant distance from a leading vehicle. Participants controlled the steering wheel to keep the car within its lane, while also responding to specific stimuli and suppressing others. The stimuli we used are:

Braking: the stopping lights of the leading car turn on. The participant has to respont to this stimulus by pressing the braking pedal;

Sign: a sign, reproducing those found in highways, appear at the top center of the screen. The sign may represent either a city or a country. A participant must respond only to one variant of this stimulus (which one is chosen at random), by operating a lever on the steering wheel.

A single simulation session lasts approximately 25 minutes, plus 5 minutes for practicing before the first session. During the simulation, the participant is presented with:

- 72 braking stimuli;
- 72 sign stimuli, of which 50% are "go" stimuli (*i.e.*, the participant must respond to them), and 50% are "no-go";
- 72 combined stimuli consisting of a braking and a sign; the signs are divided into 50% "go"and 50% "no-go".

An example of combined stimulus is shown in Figure 2. The time interval between two stimuli is drawn from a random uniform distribution between 6 and 8 seconds.

3. Questionnaires

After each session, participants completed two questionnaires. The first consists of a selection of questions from the IGroup Presence Questionnaire (IPQ)", which aims to assess the participants' perceived characteristics of the simulated environments [19]. The IPQ consists of a series of questions designed to measure different aspects of a simulation: general presence, spatial presence, involvement and experienced realism. The questions we selected are listed in Table 2 along with statistics on the responses of the two groups of participants.

The second questionnaire is the "Simulator Sickness Questionnaire", which measured participants' sickness experienced during the simulated driving activity [20]. It consists of 16 items that assess different aspects of sickness on a scale from "None" (equivalent to a score of 0) to "Severe" (equivalent to a score of 3) and is divided into three non-mutually exclusive categories: Nausea, Oculomotor and Disorientation. The score for each category is the sum of the scores of the items belonging to that category. These are then summarised by the "Total" score, which is

Figure 2: An example of combined stimulus: the car ahead is braking while a sign is shown.

Table 2

Responses to the IGroup Presence Questionnaire: Participants rated their level of agreement with the prompts of the questionnaire on a scale of -3 to +3, indicating their level of agreement with each question. Different questions rate different facets of the simulation, with INV representing involvement, REAL denoting realism, and PRES representing presence. For each question and group, we report the mean of the responses. The “p-value” column represents the p-value of a Wilcoxon test that evaluates the difference between the mean responses of the two groups. “n.s.” stands for “Not Significant”.

Question	Evaluates	Youngs	Elderly	p-value
How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)	INV	0.0	0.3	n.s.
How real did the virtual world seem to you?	REAL	-0.1	0.3	n.s.
How much did your experience in the virtual environment seem consistent with your real world experience ?	REAL	0.7	-0.4	<0.05
In the computer generated world I had a sense of ”being there”	PRES	1.0	0.4	n.s.

a weighted sum of the components. The scores of the SSQ questionnaire are summarised in Table 3, while the symptoms that the questionnaire assesses are listed in Table 4 along with the categories to which they belong.

Table 3
Mean responses (with standard deviations) to the SSQ questionnaire about sickness experienced during the simulation [20]. The total value was calculated according to the equation developed by the original authors of the questionnaire. Column p-value" represents the p-value of a Wilcoxon test assessing the difference between the responses of the two groups."n.s." stands for "Not Significant".

	Youngs	Elderly	p-value
Nausea	4.9 (7.7)	2.2 (4.1)	n.s.
Oculomotor	11.22 (16.5)	3.8 (7.4)	<0.05
Disorientation	7.2 (14.1)	4.4 (7.9)	n.s.
Total	87.5 (129.4)	61.4	n.s.

Table 4
Symptoms evaluated by the SSQ questionnaire.

Symptom	Category
General discomfort	Nausea and Oculomotor
Fatigue	Oculomotor
Headache	Oculomotor
Eyestrain	Oculomotor
Difficulty focusing	Oculomotor and Disorientation
Increased salivation	Nausea
Sweating	Nausea
Nausea	Nausea and Disorientation
Difficulty concentrating	Nausea and Oculomotor
Fullness of head	Disorientation
Blurred vision	Oculomotor and Disorientation
Dizzy (eye open)	Disorientation
Dizzy (eye closed)	Disorientation
Vertigo	Disorientation
Stomach awareness	Nausea
Burping	Nausea

4. Discussion

The hardware used for our simulation is remarkably simple, widely available, and inexpensive, especially when compared with more complex alternatives. Furthermore, from a software perspective, we have not implemented any complex behaviours for the traffic agents. Since our simulation takes place on a highway, there are of course no pedestrians. The actors in the scenario are cars, trucks, and motorbikes, each of which is assigned a randomly generated speed and occasionally overtakes the participant's vehicle. Consequently, the AI responsible for traffic management is similarly straightforward.

We believe that simplicity has distinct advantages. Nevertheless, it is essential to evaluate whether this simplicity has negative effects on the experimental activity, and, hence to answer to **RQ1**. For this reason, we statistically analysed the responses to the IPQ, to evaluate the simulation in terms of realism, presence and involvement, and to identify any difference between the two age groups in their perceptions of the simulation. The column p-value” in Table 2 shows the p-value of a Wilcoxon test used to assess a statistically relevant difference between the responses of the two groups. We could only detect a difference in the third question, which assesses the realism of the simulation: older participants perceived the simulation as less consistent with the real experience than younger participants. On the other hand, we could not find any difference between the answers to the second question, which assesses the same characteristic, that is, realism. Therefore, we believe that this point needs further investigation in future studies. Considering that the possible responses to the IPQ range from -3 to 3, we can say that the simulation is not considered particularly immersive, but it is not considered to be unengaging either. Further studies should move towards a comparison with more complex simulations, to assess whether the added complexity is a benefit to the perceived experience.

As for **RQ2**, symptoms in the categories “nausea” and “disorientation” of the SSQ questionnaire are generally minor and do not differ significantly between the two groups (Table 3). However, it should be noted the high standard deviation in the category “disorientation” for the young group, which corresponds to a high variability of symptoms. More research is needed to understand the reason why some participants experience a moderate level of disorientation, especially considering that our simulation is not very different from a normal video game that young users are likely to have experience with.

Although oculomotor disorders are not severe, they are less negligible in the young group, with a significant difference from the elderly group. This may be surprising, as we assume that younger people are much more familiar with virtual reality and video games. Therefore, one would expect fewer symptoms in this group. However, this is not the first experiment to find that older people suffer less from motion sickness than younger people [21]. Similar to the perceived realism in the IPQ, this point also deserves further investigation.

5. Conclusions

We designed an experiment, based on a driving simulator, to assess driving attention in two groups of subjects of different ages and to evaluate whether two different types of direct current brain stimulation can be used to increase attention. Our simulation, which is characterised by its simplicity in terms of hardware and software, provides a low-cost and accessible platform for studying human responses in a controlled driving environment. While we believe that simplicity offers distinct advantages in terms of accessibility and cost-effectiveness, it is critical to further evaluate whether this simplicity has any adverse effects on experimental outcomes. We evaluated participants’ experiences using two well-known questionnaires to assess the immersiveness of the simulation and motion sickness. Our statistical analysis of participant responses measured by the IPQ questionnaire revealed that older participants perceived the simulation to be less consistent with real-world experiences compared to their younger counterparts. This finding highlights the need for further investigation into the realism of our simulation and suggests that future studies should explore how additional complexity might enhance the perceived experience.

In relation to the SSQ questionnaire, we found that symptoms related to “nausea” and “disorientation” were generally very low and did not differ significantly between age groups.

Further research is needed to understand why some young participants experienced moderate disorientation, given their likely familiarity with video games and virtual reality.

Interestingly, our study found that oculomotor disorders were more pronounced in the young group, despite the assumption that they were more familiar with virtual environments. This observation is consistent with previous research suggesting that younger people are more prone to motion sickness than older individuals. This phenomenon should be investigated further to uncover underlying factors that contribute to these findings.

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