A protocol to evaluate the impact of visual distractors on driving attention using a virtual reality simulator

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Abstract

Attention is a cognitive process essential for safe driving that requires the processing of relevant stimuli while simultaneously suppressing a large number of distractors. Visual distractions, in particular, pose a high risk due to the inherently visual nature of driving and the similarity to relevant stimuli. In this paper, we propose a protocol to evaluate the effects of different visual distractors on driving attention using a virtual reality (VR) driving simulator. The protocol is composed of multiple driving tasks in a controlled VR environment that presents relevant stimuli that resemble stop signs and irrelevant distractors of varying similarity. By measuring drivers' reaction times and lane keeping under different experimental conditions, we aim to evaluate how the presence and similarity of distractions affect attention. The use of a virtual reality simulator allows safe and reproducible testing, overcoming the ethical and practical challenges of driving studies in real-world.

Keywords

virtual reality, driving simulator, attention

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1. Introduction

Driving is a complex task susceptible to various influencing factors, with distractions emerging as a significant safety concern. These distractions, which can be caused from both visual and acoustic stimuli, exert a more relevant impact when visual, due to the inherent visual demands of driving.

Efficient visual selective attention is essential for enhancing driving safety and avoiding distraction-related accidents [1, 2, 3]. Selective attention has been correlated with improved driving performance, diminished crash rates, and safer lane changes [4, 5, 6]. Additionally, attentional mechanisms, like divided attention and sustained attention, play essential roles in ensuring safe driving [7, 6].

Assessing the impact of different distractors on driving performance and to develop effective attention-enhancing strategies is necessary to enhance road safety. However, conducting studies of this nature faces inherent challenges, such as ethical concerns associated with introducing

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distractors into real-world driving scenarios, or practical ones associated with accurately measuring driving performances. For these reasons, recent years have seen a surge of interest in using virtual reality (VR) environments to overcome these challenges, offering immersive experiences while avoiding the ethical pitfalls of real-world evaluations.

Virtual reality driving simulators encompass a spectrum of configurations, ranging from basic setups with desktop computers and steering wheels [8], to sophisticated systems replicating car interiors with multi-axial vibration and shaking mechanisms [9]. Despite the advantages of advanced and immersive equipment, potential drawbacks, such as prohibitive costs, must be considered. Reproducibility, essential for rigorous scientific investigation, may be compromised by the adoption of very expensive equipment.

With this work, we propose a protocol to evaluate attention and the effect of different kinds of distractors and stimuli while driving in a simulated environment.

2. Related Work

The evaluation of driving attention has been a critical focus within transportation research, with investigations spanning both real-life driving scenarios and simulator-based studies.

2.1. Real-Life Driving Studies

Real-life driving studies offer a direct and ecologically valid assessment of driving attention. Researchers can use various data collection methods, including eye-tracking devices, physiological measurements, and in-vehicle cameras, to estimate the driver's attention.

Eye-tracking glasses have been long used to measure the movements of a driver's gaze and to examine the impact of distractions on drivers' visual attention in real-world traffic conditions [10]. Moreover, researchers have also explored physiological markers such as heart rate variability, electroencephalogram (EEG) signals, or skin conductance, to estimate the cognitive workload and attention levels during real driving [11, 12, 13]. Cameras installed in participants' vehicles have also been used. These studies allow for the analysis of driver behavior, including attention lapses, in everyday driving scenarios. For example, the "100-Car Naturalistic Study" used in-vehicle cameras to measure driver performance, behavior, environment, driving context and other factors that were associated with crashes for 100 drivers across a period of one year [14].

However, conducting real-life driving studies presents challenges such as ethical concerns, safety issues, and the difficulty of controlling experimental variables.

2.2. Simulator-Based Studies

Simulator-based studies provide a controlled and reproducible environment for the systematic manipulation of driving conditions while monitoring attention. In addition, virtual reality driving simulators provide a platform to study attentional processes without exposing participants to the risks associated with real-world driving. Attention has been studied with different types of driving simulators. The complexity can range from very simple simulators consisting of normal gaming devices, such as steering wheels and pedal boards [8, 15], to very complex and expensive systems with six degrees of freedom [16]. While the impact of visual fidelity on drivers' performance and behavior has been studied [17], the driving experience at a simulator is not determined only by visual fidelity, but also by the hardware used and the feedback provided by the simulator. Moreover, the trade-off between realism, complexity, cost, and reduced replicability should be better explored. Eventually, there is still low evidence supporting driving simulators validity [18].

Despite these considerations, driving simulators have been used extensively in transportation research. For example, they have been used to evaluate drivers' attention [8, 19] and especially to evaluate how attention can be affected by various parameters such as the surrounding environment [20, 21], speed [22], and even drowsiness [23]. While all these aspects could also be investigated when driving in reality, in a simulator it is much more practical to change some parameters, such as the environment, and ethically acceptable to test under dangerous conditions, such as high speed and drowsiness.

Another example of the possible use of a simulator is the manipulation of the cognitive workload through task complexity and environmental conditions. For example, Son *et. al.* studied the effects of cognitive workload on the behavior of older drivers during simulated driving [24]. Cantin *et. al.* also investigated the effects of age and driving complexity on the mental workload in a driving simulation [25].

3. Materials and Methods

While driving, we are constantly exposed to various stimuli, such as traffic lights, road signs, other vehicles, and pedestrians. Simultaneously, numerous distractors, such as advertisements or phone notifications, must be ignored to ensure safe driving. However, this task is challenging, as distractors can often resemble important stimuli. Additionally, driving itself is a complex activity that requires sustained attention.

In this work, we propose a protocol to assess the impact of different types of distractors on driving attention. Specifically, we investigate distractors that vary in similarity to a crucial stimulus, resembling a *stop* sign. The evaluation is conducted using a driving simulator, which provides the necessary control over stimuli and distractors, something that would be nearly impossible to achieve in real-world driving conditions. While a real-world setup might offer higher ecological validity, the use of a simulator allows precise control and analysis of various factors, which is critical for scientific research.

3.1. The Experiment

The virtual environment features an extra-urban two-lane road within a rural landscape. The driving simulation uses a first-person perspective and takes place during day-time. Task-irrelevant lateral road signs and other moving vehicles are rendered in the environment. The road circuit forms a loop, predominantly rectilinear with sharper bends at its extremities, allowing drivers to re-enter the route.

Our experimental activity consists of three different kinds of blocks, called *pure*, *mixed-easy*, and *mixed-hard*. Each kind of block corresponds to a driving session taking place in the environment described above. During each driving session a participant is subject to different

(a) (b)

Figure 1: The two kind of stimulus. During each session one of the sign is used as stimulus, the other one as *hard distractor*.

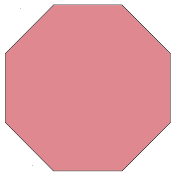

Figure 2: The sign used as *easy* distractor

kinds of event, also called trials. Different blocks are composed of different kinds and number of trials.

The pure block is composed of 60 trials. In this case, trials can be of two kinds: target-present and target-absent. During a target-present trial, one of the stimuli shown in Figure 1, designed to resemble a classic stop sign, is presented. Half of the participants is shown the stimulus from Figure 1a, while the other half is shown the stimulus from Figure 1b. This approach ensures that the experiment is not biased toward a specific configuration, such as the red portion appearing in either the lower or upper part of the stimulus.

We ask participants to respond to the stimulus by pressing the brake pedal. When responding correctly, the sign disappears and thus the trial ends; however, this also happens after 2 seconds in absence of any response. During a target-absent trial no stimulus is shown to the participant. This serves to break any expectation of the presentation of a trial. A new trial takes place after a random time interval sampled from an uniform distribution between 4 and 6 seconds. A pure block is composed of 30 target-present and 30 target absent trials.

Mixed blocks work like the pure block, but are composed of 120 trials in total, subdivided in 30 target-present trials, 30 target-absent trials, 30 distractor-present trials, and 30 distractor-present and target-present trials

During distractor-present trials, a distractor is displayed. A mixed block can be classified as either "hard" or "easy". In the "hard" condition, the distractor is one of the sign from Figure 1 (that not used as stimulus), closely resembling the target. In the "easy" condition, the distractor is less similar to the target, featuring lighter colors and lacking any white sections, as shown in Figure 2.

During distractor-present and target present trials both a distractor and the target are shown.

Regardless of the type of block, the target and the distractors appear in the upper part of the screen, either on the left or on the right.

During each experimental session, participants complete a pure block, a mixed hard block, and a mixed easy block, lasting 7, 21, and 21 minutes, respectively. The order of the blocks is randomized and varies for each participant. The session also includes a 2-minute training phase to allow participants to familiarize themselves with the simulator, along with two short breaks between the blocks.

To measure the performance of the participants, we assess the following metrics:

1. **Reaction time** – the time it takes for participants to respond to stimuli, that is, the time it takes to press the brake when a stimulus appears.
2. **Lane keeping** – the ability of participants to maintain their position within the lane, reflecting their overall control and focus during the driving task. Lane keeping is assessed using the "wheel error" metric, which measures the difference between the angle of the front wheels and the angle required to follow the optimal trajectory provided by the simulator. The standard deviation of these measurements, calculated within a rolling window, serves as the indicator of lane-keeping performance.
3. **Accuracy of responses** – the correctness of the participant's reactions to stimuli, particularly in distinguishing between relevant stimuli and distractors.
4. **Error rates** – the frequency of incorrect responses or missed stimuli, which provides insight into how well participants can ignore distractors while focusing on important driving cues.

3.2. The Simulator

The simulator setup we propose is rather minimalistic. We use a gaming pc powered by an Intel Core i7-10700K 3.8 GHz, Nvidia Geforce RTX 3080 (10GByte), and 32 GByte of RAM, with three 24 inches widescreen monitors (1920 x 1080), arranged in a semi-circular configuration. The lateral monitors are positioned at 120° relative to the central monitor to realistically simulate both central and peripheral fields of view, allowing for a comprehensive horizontal field of view of 210°. Car controls are simulated using standard racing game equipment, including a Logitech G29 Driving Force steering wheel, pedal board and gear shift lever (which is not used during this experiment). The driver sit in an adjustable office chair.

We use the CarnetSoft driving simulation software (version 7.1), which has previously been employed in research on visual attention and inhibitory mechanisms during driving [15, 8]. To limit the variability during the simulation, and hence ensure experimental control, we place constraints on driving parameters. In particular, vehicle speed was limited between 50 and $80km/h$, with an acceleration rate of $6m/s^2$, which was chosen after several tests, to reproduce the feeling of a real driving experience. We use pedal pressure thresholds to differentiate between goal-directed and incidental pressures: braking is recorded when the gas pedal is pressed less than 30% of its full range, while acceleration happens when the gas pedal pressure exceeded 70%. Data sampling for collection occurs at a frequency of 100 Hz.

The virtual environment depicts an extra-urban, two-lane road in a daytime rural setting, with drivers experiencing right-hand traffic from a first-person perspective. The road features task-irrelevant lateral road signs and other vehicles traveling in the same direction. Audiovisual stimulation matched the environment to enhance realism and engagement. The entire setup is implemented in a darkened and controlled laboratory, ensuring isolation from external stimuli and consistent experimental environment.

4. Questionnaires

We utilize questionnaires to evaluate various aspects of the simulation and to assess participant characteristics. We evaluate driving habits of the participants using both open and multiple-choice questions. More specifically, participants are asked to indicate how many years it passed since they obtained their driving license, if they are currently driving, and, in case, how many times they drive per week and how many kilometers they travel on average. Finally, we ask about the usage of vision correction methods.

Moreover, sleep quality is evaluated using open questions regarding the average sleeping hours per night and, more specifically, how many hours were slept and – if any – how many awakenings occurred the night before the experiment. Furthermore, we ask participants to indicate how they rate the quality of their sleep that night on a 10-point Likert scale (from 1 = very poor to 10 = very good). Ultimately, we ask them to indicate if they assumed any stimulating substance (*e.g.,* coffee) within the two hours preceding the experiment.

To evaluate previous video-games experience we use a translation in Italian of the questionnaire presented by Stichcombe et al. [26]. This brief questionnaire includes open and multiple-choice questions, as well as Likert-scale questions on video-games expertise - in general - and on racing video-games expertise - in particular.

The experience of presence – here intended as the construction of a spatial-functional mental model of the virtual environment within an embodied cognition framework [27] – is measured by adapting four selected items taken from the Igroup Presence Questionnaire (IPQ). More specifically, the selected items are intended to measure the following constructs: one item for Involvement [28], two items for Experienced Realism [29, 30], and one item for General Presence [28]. All elements are evaluated on a 7-point Likert scale; the anchors of the extremities are defined by labels adapted to the content of the element itself, in a range from -3 (defining low experience of presence) to + 3 (defining high experience of presence).

To assess whether the typical symptoms of simulator sickness influence driving performance, we ask participants to complete an adapted version of the Simulator Sickness Questionnaire (SSQ) [31]. It comprises 16 items - concerning the main experienced oculomotor, disorientation, and nausea-related symptoms when using a virtual simulator - to be evaluated on a 5-point Likert scale.

5. Conclusions

This paper presents a protocol for assessing the effects of visual distractors on driving attention using a driving simulator. The proposed methodology evaluates how distractors that resemble traffic signs influence attention and performance in a safe, reproducible setting, overcoming the limitations of real-world studies. By incorporating different distractor difficulty levels, the protocol reliably tests attention under various cognitive loads. It is cost-effective and accessible, and is adaptable for further investigation with additional sensors like eye-tracking or physiological sensors. This framework supports research into visual distractions' impact on driving, contributing to road safety advancements.

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