Hypovigilance in Limited Self-Driving Automation: Peripheral Visual Stimulus for a Balanced Level of Automation and Cognitive Workload

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***Abstract*— Higher levels of vehicle automation might lead to a reduction in driver situational awareness, as driver intervention to control the vehicle is only demanded in novel, previously unencountered situations that the automation might not be able to handle. In this paper we address this question by presenting a study on continuous, in-vehicle visual stimulus to reduce driver reaction time after a period of hypovigilance. We relied on peripheral vision, which is processed subconsciously, to implement an unobtrusive method based on luminescence. Data analysis showed a tendency among drivers to respond faster to a Take Over Request when their peripheral vision detected the stimulus.**

I. INTRODUCTION

The long term effect of distraction by non-driving tasks in a driving context has been investigated in several works [1, 2, 3]. The studies examined differences in driver reaction time (RT) to visual stimuli before, during and post-distraction, confirming that RT did not return to its baseline performance level immediately after a period of distraction. Research also concluded that for a driver to reestablish focus on the road could take up to 27 seconds after finishing a highly distracting task and up to 15 seconds after a moderate one [1, 2].

Moreover, as stated in [4], several studies have shown that drowsiness and hypovigilance while manually operating a vehicle frequently occur during highway driving and might be responsible for serious road accidents [5].

Similarly, limited self-driving automation, or Level 3 according to levels of automation of the National Highway Traffic Safety Administration (NHTSA) [6], might lead to a reduction in driver situational awareness, as driver intervention to control the vehicle is only expected in cases that have not previously been considered in the algorithms and that the automation might not be able to handle.

This decrease in driving workload and the resulting reduction in situational awareness needs to be compensated by new methods of providing unambiguous continuous feedback that also ensures a good driving experience and joy of use [7]. Therefore, research in the field is imperative to guarantee the optimum level of automation that is balanced by an appropriately demanding cognitive workload.

In this paper we address this question by presenting a study on continuous, in-vehicle visual stimulus to reduce the driver's reaction time after a period of hypovigilance potentially involving eyes or mind off road during limited self-driving automation.

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We base our test design on existing literature on attentional resources that focuses on abrupt changes in the periphery, utilizing these findings to create an application that operates in the driver's peripheral view and draw conclusions based on these tests. As described in [8], attention is related to one's acute awareness of interesting or prominent information. Abrupt changes in the periphery can direct focal attention and also enable us to respond to changes that might require a shift of focus, thus being able to respond appropriately to new information when necessary.

We use peripheral vision, which is processed subconsciously [9], to implement an unobtrusive method based on luminescence. This approach makes it possible to expose the driver to an intelligible continuous stimulus in limited self-driving automation that becomes only conscious in the event that driver intervention to control the vehicle is required. We therefore ensure a good driving experience and joy of use of the automation.

We evaluate this concept and investigate whether the system has an impact on reaction time after a period of hypovigilance. To this end we define and test the following null and alternative hypotheses:

H0: During limited self-driving automation, in-vehicle exposure to a continuous, unobtrusive luminescence stimulus does not affect the driver response time to a Take Over Request (TOR).

H1: During limited self-driving automation, in-vehicle exposure to a continuous, unobtrusive luminescence stimulus affects the driver response time to a TOR.

II. RELATED LITERATURE

As mentioned in the previous chapter, research in the field of attentional resources has been performed in several works. For example, it has been stated that boredom disposition varies individually [10], consequently affecting situational awareness reduction.

Prolonged monotonous driving leads to a steady reduction in vigilance. However, drivers do not perceive this decrease in attention; sometimes even feeling that their vigilance has increased [11]. Road design and roadside variability also affect vigilance on monotonous roads. During a state of hypovigilance, a decrease in driving performance is manifested in lane positioning, duration of lane change, blink frequency, heart rate variability and non-specific electrodermal response rates [12].

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The authors in [13] showed that hypovigilance can arise even during a 12 minute vigilance task. There is also a significant correlation between multitasking performance and driver response time to a TOR in autonomous driving [14].

In several works reaction time to a certain stimulus has been stated as a valid metric to measure levels of inattention [15, 16]. This time can be affected by the emotional state of the person, as interpreted in [17], and also by the kind of task being performed. For example, reaction time differs depending on whether the acts are trained or uncommon, the latter requiring a longer mental processing time [18].

Research on parameters that affect reaction time showed that when the stimulus is visual, reaction time remains stable at 131 ms on average, being unaffected by the individual's age. For other types of stimuli, however, age was found to have an effect on reaction time [19]. A further study showed that reaction time to auditory stimuli is faster than to visual ones, being around 19.6 ms. Individual gender affected the resulting reaction times, being about 24 ms faster in males than in females [20].

Experiments performed to investigate reaction times by using colors as visual stimuli have shown that reaction time is not affected by the color intensity [21]. However, keeping color active as a visual stimulus can hold drivers' attention in the form of subconscious information independently of their awareness to it [22].

We contribute to the state of the art by presenting a system based on peripheral visual stimulus to increase the situational awareness of the driver using subconscious processing.

III. SIMULATION PLATFORM IMPLEMENTATION

In order to implement the required scenario, we selected a section of the city of Vienna from OpenStreetMap (OSM) [23] to combine the corresponding road networks with the Unity 3D game engine [24] and the CityEngine procedural modeling tool [25].

Several terrain and building models were accessed from the Geodata of the city of Vienna [26] in order to determine their height. Corresponding conversion tools were used, data imported, program settings applied and subsequently modeled (see Fig. 1). The corresponding simulation controlled vehicles (SCV) were then created to be defined as an ego vehicle or vehicles in the scenario. Fig. 2 shows the implemented ego vehicle from inside.

Fee-based assets are offered in Unity3D, which can implement the OSM data directly into Unity3D. A solution creating nodes and their links for the use of vehicles was applied within the framework of this work as shown in Fig. 3. These nodes were then made invisible for the simulation. The SCV followed the nodes and links in order to simulate autonomous driving behavior.

Figure 1. Model in CityEngine from the surroundings of the University of Applied Sciences Technikum Wien, in Vienna, Austria.

Figure 2. Implemented ego vehicle in the simulation platform and surrounding scenario.

IV. EXPERIMENTAL SETUP

A. Apparatus

A simulation platform facilitated the testing of the proposed approach. It consisted of a low-fidelity driving simulator with projector visualization that provided a driver-centric perspective and included realistic graphics that represented roads, traffic lights and other signs. In addition the simulator was able to render potential damage and offered the possibility to modify the type of vehicles as well as the scenario.

We implemented an ambient light as unobstrusive peripheral visual stimulus. It consisted of LED lights that switched colors every ten seconds. Fig. 4 illustrates the general experimental setup with the luminescence.

B. Experimental Procedure

There were a total of 28 participants in the study (15 male, 13 female, mean age = 28.9, SD = 10.4). Prior to the start of the experiment the participants were informed about the procedure without mentioning the purpose of the luminescence.

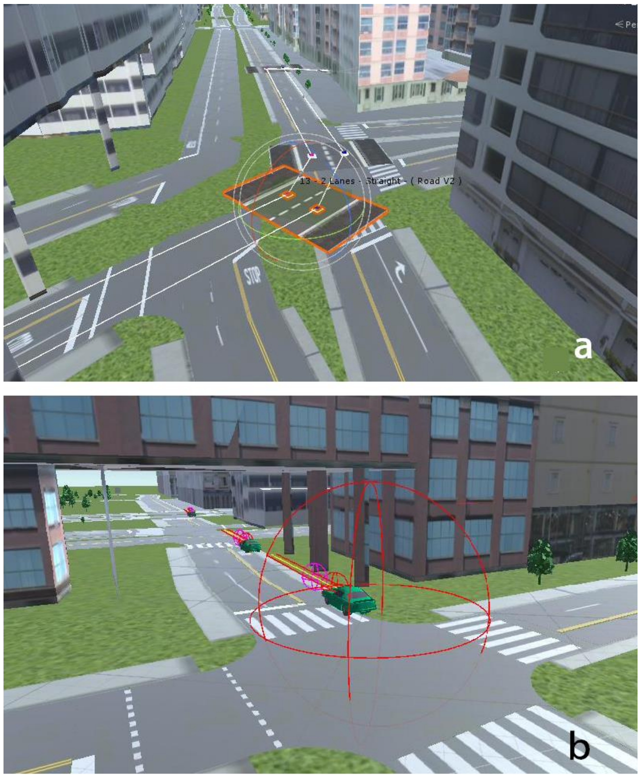

Figure 3. a) Nodes creation for the simulation controlled vehicles and b) section of the platform showing the generation of the simulated vehicles.

They were instructed to sit in the vehicle and perform the tasks that they considered convenient while driving in a limited self-driving automation. They were also informed about the potential driver intervention to control the vehicle necessary to the level of automation in the experiment.

The vehicle began moving at the same time the luminescence was activated. After 20 minutes, an acoustic signal indicated that the driver should take over control of the vehicle. To indicate their awareness of a manual transition request, the participants had to press a button located on the steering wheel. The time from the acoustic signal until the activation of the button was logged. The process was repeated an additional time, alternating the order of activation of the lights for each participant to avoid bias.

As vehicular control was not required for an extended period of time during the tests, the participants looked at the scenery without steering or were engaged in several activities with their mobile phones, such as playing games or talking. After finalizing the quantitative data collection, they were asked about their subjective opinion regarding the system.

C. *Data Analysis*

To analyze the data, we compared the values for the logged parameter reaction time for the different conditions with and without visual stimulus and proofed their statistical significance using a paired t-test. We also evaluated the subjective collected data. The standard alpha level for significance of .05 was selected.

Figure 4. Simulation set up showing the luminescence as visual stimulus.

V. Results

Results regarding the reaction time to the TOR are shown in Table 1. The difference between the mean reaction time was not statistically significant and therefore the null hypothesis was accepted and the alternative hypothesis rejected.

A slight increase in the reaction time when the luminescence was activated could however been observed, it being 61 milliseconds faster. Fig. 5 shows the mean values in a Gaussian distribution with and without luminescence. Participants reacted faster to the TOR with luminescence than without luminescence.

Fig. 6 and 7 show the comparison of reaction times among individuals and as average value, respectively. As one can see, some individuals were so immersed in performing non-driving related tasks that they needed extra time to free their hands to respond to the TOR.

Results from the subjective evaluation showed that the implemented scenario was recognized as the surroundings of the university by all participants. Five people (17.8%) considered the luminescence approach to be uncommon but not disturbing.

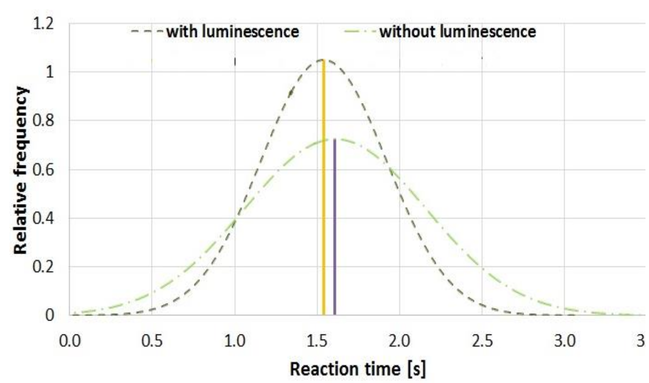

Figure 5. Comparison of the mean values in a Gaussian distribution, with and without luminescence.

TABLE I. COMPARISON OF REACTION TIMES TO A TOR WITH AND WITHOUT THE PROPOSED SYSTEM

Metric	***Without luminescence***		***With luminescence***		***T-Test (α =0.05)***	
	Mean	SD	Mean	SD	*t*(27)	ρ
Reaction time	1.61	0.55	1.54	0.38	0.49	0.63

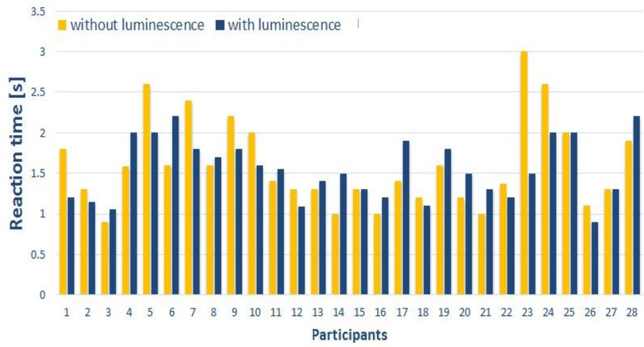

Figure 6. Individual comparison of reaction times with and without luminescence.

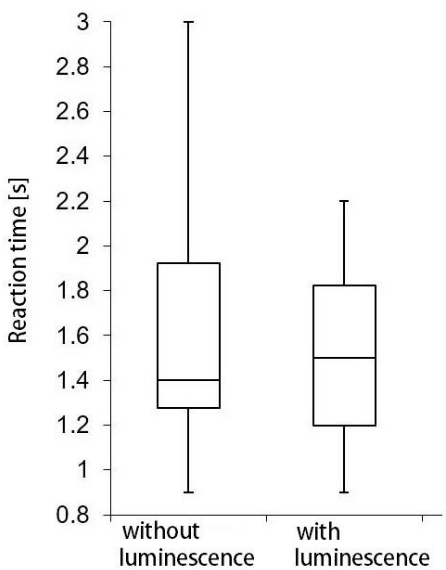

Figure 7. Comparison of mean values of reaction times with and without luminescence.

VI. Conclusion and Future Work

The results of the evaluation of the proposed approach did not show a statistical difference between the reaction time mean values with and without luminescence. However a tendency could be observed of slightly faster response time to a TOR when the peripheral vision detected the luminescence.

The technology presented in this paper could be helpful in limited self-driving automation, as visual peripheral stimulus might increase the reaction times to a TOR without being obtrusive.

Further research will focus on the driver's response to the perceived stimulus with a larger participant sample size. Previous research showed that hypovigilance can arise during a short time period of 12 minute [16], indicating this that our 20 minutes testing time should be enough to obtain conclusive results. Experiments with a longer simulated driving time will be performed in future work.

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