Flicker effect on visual performance and driving behavior

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Abstract. In tunnel driving, drivers may perceive certain visual disturbances due to the known flicker effect. Besides, the modern tunnel lighting solution applies various and/or new lighting sources, layout designs, luminance distributions, mounting systems, etc., which might further affect the drivers. In this research we aim to investigate the potential effects on drivers' visual performance as well as driving behaviors caused by flicker in tunnel driving. The ultimate goal is to ensure the driving performance and to enhance the driving comfort by minimizing the flicker effect, while keeping road safety as the top principle and energy consumption/efficiency consideration.
This experimental study has been conducted in a VR (virtual reality) environment. Participants wear a HMD (head-mounted display) and perform several driving tasks in a motion platform-based driving simulator. An external LEDs (light emitting diodes) array module has been implemented and integrated with the HMD for exposing the driver to some vivid flicker stimuli. An eye-tracking module has been installed in the HMD for observing the eye movements of the drivers. In addition, some important driving parameters, e.g. vehicle trajectories, accelerating/braking logs, speed control, etc., are recorded for further analyses.
In the present study, we have constructed a VR-based driving simulation with external LEDs flicker stimuli in road tunnel driving scenarios. Driving behavior, visual performance and fatigue, eye movement, and subjective assessment are evaluated under two lighting conditions (0 Hz and 16 Hz flickering).

Keywords: flicker, fatigues, tunnel lighting, visual performance, driving behavior, simulator study

1. Introduction

Road safety has evolved into a great threat to humans globally. According to the Global Status Report on Road Safety (WHO, 2018), the number of road traffic deaths on the world roads remains unacceptably high. The literature has identified various factors impairing driving performance and causing crashes, such as fatigue, e.g. caused by road environments and driving periods (Kee et al., 2010). Factors impairing driving performance could even be related to the road infrastructure, such as flashing lights or signs (Ronchi and Nilsson, 2013). In the present study, we addressed possible impairments caused by a flickering tunnel lighting.

While driving through a tunnel, the arrangement of light sources may cause flicker. Modulations of light, temporal as well as spatial, can cause visual seizures and migraine episodes (Wilkins et al., 2010) leading to traffic accidents. The perception of flicker (Kelly, 1972) as well as symptoms generated by flickering light (Wilkins et al., 2020; Zhao et al., 2020) have been found to depend on the frequency of the flicker. In addition, flickering light may severely impact visual comfort (Bullough et al, 2011), which then could affect cognitive performance in the driver.

Flicker frequencies in tunnel lighting depend on the shape of the light source, whether it is more a light band or more a spot like source, on the mounting distance of neighboring light sources, and on the driving speed. According to the International Commission on Illumination (CIE,2004) light with flicker frequencies in the range between 2.5 Hz and 15 Hz should be avoided in order to reduce negative consequences of the flickering light on traffic safety. This recommendation, which has been included in various regulations on traffic lighting across the world implies a careful matching of light source shape, mounting distance and driving speed. (Lehman, B., & Wilkins, A. J. ,2014). Chen et al., (2019) suggest to use a Low Mounting Height Luminaires (LMHL) to reduce the flicker effect. However, in common road tunnels light sources are usually set on the top ceiling.

In this study, we conducted experiments in a driving simulator aiming to investigate effects of tunnel flicker on driving behavior, visual discomfort, and distraction.

2. Method

2.1 Instrumentation

The experimental equipment is a six degrees of freedom driving simulator designed by our laboratory as shown in Fig. 1. In the simulator, participants are equipped with a head mounted display HMD (HTC Vive). For the generation of flicker, LEDs have been installed inside the HMD. The driving scene is set up by using unity 3D (Unity Technologies, San Francisco, California, USA). An example of the scene is given in Fig. 2 showing the view as seen by the participant and before starting the experiment (no car ahead). Two different frequencies of tunnel lighting flicker were used, which are 0 Hz and 10 Hz.

Figure 1. *Driving simulator with a 6DOF motion platform.*

2.2 Subjective measurements

Two questionnaires are applied in this study. The NASA-TLX is used to analyze the mental load while performing the driving task. Besides, the driving behavior scale is used to record driving performance and to evaluate driving fatigue. The driving behavior scale includes two parts. One is the driving behavior questionnaire (DBQ) which is primarily about looking at the so-called frequency of driving errors. The other is the driving behavior inventory (DBI) which is to classify the kind of driving errors. The driving behavior inventory (DBI) was developed in 1989 (Gulian et al., 1989). According to the criteria of parallel analysis and screen tests in DBI results, it was used to evaluate the driver's subjective stress perception. There are five dimensions: driving aggression, dislike driving and related anxiety, driving alertness, irritation when overtaken, and overtaken tension. The driver behavior questionnaire (DBQ) is a widely used instrument for measuring self-reported driving behaviors (Reason et al., 1990).

2.3 Objective measurements

Objective driving behavior data are collected using the simulation software, mainly considering the data recorded by the steering wheel rotation angle and the car body offsets. Also, eye movements are recorded for computing fixations and other eye parameters which are used in the analysis of fatigue of the driver.

2.4 Experimental protocol

Before the experiment starts, the monitoring personnel informs participants about the relevant matters needing attention, the purpose of the task, and then give the participants exercise trials on the driving simulator so to familiarize them with the instrumentation. After participants completed a questionnaire on personal data, participants' visual acuity is recorded.

Participants were instructed about their task, which is to follow the vehicle driving ahead at a constant distance. The distance from the target vehicle is displayed by colored signal, meaning that the green color represents a fair distance from the vehicle in front, and red indicates that it is too close or too far away from the target. The speed of the vehicle ahead was varied and was within a range of $80\ km/hr \pm 10$. During driving, there will be a sign indicating the maximum speed limit. The car following task will be regarded as a secondary task. When the virtual driver of the front vehicle stepped on the brake or changed the road, the participant also had to make corresponding responses.

Figure 2. *Sample driving scene in the tunnel with flicker effect made by Unity 3D.*

Figure 3. *The immersive VR driving task while wearing the HMD.*

3. Results

The data collected with the software and obtained from the questionnaire was used to analyze whether there is a significant difference in effects caused by the two different flicker frequencies. Data were collected in a total of 20 participants all of them having a driver's license. The two different frequencies of the flickering light were found to affect mental workload and driving behavior differently. We can conclude that at a flicker of 10 Hz, the driver is more likely to be distracted and feels a higher sense of fatigue. Fixations, pupil diameters, vehicle center line deviations, and steering wheel rotation amplitudes were also significantly increased when driving with a 10 Hz flickering light than with the other frequency.

4. Discussion

From the results, we know that the stroboscopic effect caused by the lighting settings at the 10 Hz has a stronger impact on driving. In addition to subjective factors, the 10 Hz flicker has an impact on driving reactions and behavior. When driving with a 10 Hz flicker, the performance in the following task is relatively poor. Given results of our experiment, tunnel lighting settings should avoid this frequency to improve driving safety.

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