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Effects of apparent image velocity and complexity on the dynamic visual field using a high-speed train driving simulator

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ABSTRACT

Train driving is a highly visual task. The visual capabilities of the train driver affects driving safety and driving performance. Understanding the effects of train speed and background image complexity on the visual behavior of the high-speed train driver is essential for optimizing performance and safety. This study investigated the role of the apparent image velocity and complexity on the dynamic visual field of drivers. Participants in a repeated-measures experiment drove a train at nine different speeds in a state-of-the-art high-speed train simulator. Eye movement analysis indicated that the effect of image velocity on the dynamic visual field of high-speed train driver was significant while image complexity had no effect on it. The fixation range was increasingly concentrated on the middle of the track as the speed increased, meanwhile there was a logarithmic decline in fixation range for areas surrounding the track. The extent of the visual search field decreased gradually, both vertically and horizontally, as the speed of train increased, and the rate of decrease was more rapid in the vertical direction. A model is proposed that predicts the extent of this tunnel vision phenomenon as a function of the train speed.

Relevance to industry: This finding can be used as a basis for the design of high-speed railway system and as a foundation for improving the operational procedures of high-speed train driver for safety.

1. Introduction

Drivers must constantly scan environment to obtain enough visual information to safely control their vehicle. Much of what we know about driving and visual performance comes from research studies on car drivers. Studies show that visual information is the most important source of information for any driver (Sivak, 1996). Much research has been undertaken to analyse driver visual performance, including individual factors, such as how visual performance is affected by the driver's age (Leversen et al., 2013; Munro et al., 2010; Scott et al., 2013), gender (Sarkin et al., 2013); or the presence of a vision disease (Crabb et al., 2010; Owsley, 1998). Other research has tested the effects of technology factors on visual performance, such as the influence of cell phone use (Rudin-Brown et al., 2013), the influence of an MP3 player use (Lee et al., 2012), the influence of a new in-vehicle equipment (Birrell and Fowkes, 2014), or the influence of an out-vehicle sign(Liu, 2005; West et al., 2010).

Previous research has either focused on the role of vision in driver safety or on the role of vision in driver performance (Levi et al., 2010) and most of this work has focused on road traffic. Few studies have investigated the visual behavior of train drivers, and these include investigating the glance behavior of signal, ahead, in-cab and landscape (Luke et al., 2005), and studying the visual skills of urban train driver in Australia (Naweed and Balakrishnan, 2013). Train driving has unique characteristics, for example, the train can only move forwards along the track, it cannot overtake another train, it cannot leave the track, and it can travel faster than a car. Consequently the driving information that a train driver must process is different to that of a car driver.

There are three typical working stages of the train driving process:

(1) The traction stage where the driver speeds up the train and reaches an authorized speed.
(2) The normal operation process stage, when the driver drives the train at the authorized speed and ensures that the train adhere to the timetable.
(3) The braking process, when driver slows down and stops the train.

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In all of these stages, the driver receives and processes different types of visual information from inside and outside of the vehicle. The outside visual information mainly includes signals, railway conditions, railway stations, and the landscape. The inside visual information mainly includes reading the air pressure gauge, speed indicator, clock, and other displays. Beiyuan et al. (2005) used an eye tracking system to test the visual behavior of a passenger train driver and found that the main visual task of the train driver is monitoring the railway track condition. The eye fixation was mainly attracted by the outside visual information. Eye fixation to the inside visual information only occurred when the instrument reading changed, and such changes commonly occurs in the traction stage and the braking stage.

Previous research has shown that use of a high-speed train simulator yields results for visual performance that are comparable to those obtained from a real train (Engström et al., 2005). For security and efficiency reasons, researchers usually prefer using simulators to using real vehicles, for example, Shinoda et al. (2001) examined drivers' abilities to detect stop signs in a virtual environment; Victor et al. (2005) used simulators to determine how the eye movements are influenced by different in-vehicle task types (visual and auditory), such as increasing the in-vehicle task difficulty, and the driving task complexity; and Strayer et al. (2003) examined the visual effects of hands-free cell phone conversations on simulated driving.

When driving a high-speed train in a virtual simulation system, most of the driver's visual information is dynamic information. Instrument readings constantly change, and the perspective that is rendered by computer also changes frequently. The driver looks attentively at the rail conditions to obtain the important information, such as the signal lights and railway signs. We can use an eye tracking system to record and analyze the visual information of high-speed train simulator drivers.

Eye movement plays a crucial role in visual information processing. Fixations, saccades, scanpaths and pupil size are the eye movement indexes of the driver's visual attention (Duchowski, 2007; Poole and Ball, 2006). All of these indexes can reflect the interaction states of the driver and the driving situation (inside and outside of the vehicle), and the indexes can also reflect the driver's physiological and psychological state (Ji et al., 2004). In the indexes that are mentioned above, fixations have many of their own metrics: the number of fixations, the fixations per area of interest and the fixation duration, among others. The number of fixations relates to the efficiency of visual search, and the greater the number of fixations the less efficient the search strategy (Goldberg and Kotval, 1999). The fixation duration is the time between two saccades, and a longer fixation duration indicates that the object is more engaging in some way or that there is difficulty in obtaining the information (Just and Carpenter, 1976). The fixations per area of interest show whether a specific area is noticeable or not. The choice of a suitable metric depends on the context. Because a virtual scene is rendered and appears on the screen as a plane figure, it easy to divide it into special areas and then count the duration of fixations per area of interest as the metric with which to study the visual behavior of the high-speed train driver.

There has been little investigation of the visual behavior of a train driver. Previous researches mainly investigated drivers' visual behavior of limited visual areas rather than the visual characteristic of whole visual field. The limited visual areas, which including ahead, signal, track and in-cab (Luke et al., 2005), are indispensable to driving a train. Furthermore, a train travels through both urban and rural areas, and the urban scenes have more visual elements, such as building, than the rural scenes, consequently the dynamic images of the urban scenes are more complex than the images of the natural scenes. The present research try to investigate the role of the apparent image velocity and complexity on the whole visual field of the participants using a high-speed train simulator. In a high-speed train simulator, the high-speed railway virtual scene provides a simulated driving environment, and it plays the most important role in the interaction of the simulator. In the present study, an eye tracking system was used to study the visual processes of the participants at different speeds and at different kind of scenes. The goal of the study was to determine the relationships of a high-speed train driver's dynamic visual field with the train velocity and the complexity of the scene.

2. Method

2.1. Participants

The participants were twelve male volunteers (average age, 23 years). All of the participants had normal vision and they did not wear eyeglasses during the experiment. The participants were not real high-speed train drivers, but they were trained to be familiar with driving the high speed train, they all understood the regulation of high speed train driving operation, the meaning of the railway signals and the in-cab instruments, and the way to operate the controllers on the driver desk. The participants were able to understand the test procedure. Before the test, they were all in good physical and psychological condition.

2.2. Apparatus

The experiment was conducted with a high-speed train simulation system. The system is a hardware-in-the-loop high-speed train simulator with controllers and display panels that are equipped with equipment from a real high-speed train. The controller and the display panels are movable and can be placed in the most ergonomic position, to avoid disturbing the operation of the participants. To the right of the two display panels is a train speed indicator and to the left is a touch screen displaying five virtual buttons with different colors. The system has a 52 inch 1080p LCD monitor that is used to display the virtual scene with a display size of 126 cm wide and 80 cm high. The simulator comes with a real driver seat, the seat is adjustable to make sure the participants can find the most comfortable sitting position and to ensure the distance between the monitor and the eyes of the participants is 2 m. The simulator set-up is shown in Fig. 1.

The visual behavior of the participants was recorded by an SMI iView X HED head-mounted eye tracking system. The system is a non-invasive, video-based eye tracking system. It uses the corneal reflection and the center of the pupil as features to track the eye movements. The eye tracking sampling rate was 200 Hz and the tracking resolution is smaller than 0.1°.

2.3. Test scenarios

The experiment 3D database was a 25-km long railway line. The database included all of the high-speed railway system elements, such as tracks and subsidiary facilities of the railway system, and natural landscapes and urban scenes on both track sides. The first 2 km of each train journey began with urban scenes after which landscapes were seen. Examples of the urban and natural landscapes for the experiment scenarios are shown in Fig. 2. When the simulator was running, the frame rate of motion pictures was locked to be 60 Hz to ensure the quick changes in the image, and the motion pictures were rendered to be high quality with a resolution of 1920 pixels in width and 1080 pixels in height.