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The impact of tunnel design and lighting on the performance of attentive and visually distracted drivers

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ABSTRACT

The crash risk in tunnels is lower than on the open road network, but the consequences of a crash are often severe. Proper tunnel design is one measure to reduce the likelihood of crashes, and the objective of this work is to investigate how driving performance is influenced by design factors, and whether there is an interaction with secondary task load. Twenty-eight drivers participated in the simulator study. A full factorial within subject design was used to investigate the tunnel wall colour (dark or light-coloured walls), illumination (three different levels) and task load (with or without a visual secondary task). The results show that tunnel design and illumination have some influence on the drivers' behaviour, but visual attention given to the driving task is the most crucial factor, giving rise to significant changes in both driving behaviour and visual behaviour. The results also indicate that light-coloured tunnel walls are more important than strong illumination to keep the drivers' visual attention focused forward.

1. Introduction

The crash risk in tunnels is lower than on the open road network, but the consequences of a crash are often severe (Leitner, 2001; Kirkland, 2002; Carvel and Marlair, 2005). It is therefore of high importance to ensure high safety standards in tunnels. This is achieved partly by reducing the probability of crashes and partly by reducing the consequences of crashes or fires. The former involves tunnel design, traffic regulations, appropriate facilities (ventilation system, lighting and interior) and maintenance, whereas the latter involves proper emergency facilities and fire-resistant structures (Mashimo, 2002). In this study we focus on crash prevention and investigate in which way different levels of illumination and brightness of the tunnel walls influence the behaviour of attentive and visually distracted drivers.

Tunnel lighting regulations are complex with different lighting levels in different zones of the tunnel and with different requirements in different countries. The requirements on lighting also depend on the traffic intensity, the speed limit and the outdoor conditions (day/night). Most countries use CIE Report 088:2004 (CIE, 2004) as a base. Common for all regulations is that there is a requirement on the luminance of the road surface, but not for the walls or the roof. For example in Norway and Sweden the regulations recommend the use of white walls up to a certain height, but without mentioning any figure. The illumination of a tunnel can substantially change the impression on the driver, but, to the best of our knowledge, there is no previous research that investigates how tunnel illumination affects driver behaviour. In fact, very limited research has been devoted to the analysis of driver behaviour in tunnels at all. The possibility to use the tunnel walls to convey information to the drivers was suggested by Carmody (1997), who proposed vertical stripes for speed information and horizontal stripes for gradient information. Manser and Hancock (2007) investigated in a simulator how speed can be influenced with the help of patterns and different textures on the roadside. They found that the presence of texture had an attenuating effect on speed in general. Patterns with decreasing width led to gradually decreased speed, while the opposite was true for patterns with increasing width.

Most research efforts have been allocated to accident analysis. Both in Norway (Amundsen, 1994; Amundsen and Engelbrektsen, 2009) and in Austria (Nussbaumer, 2007) it has been found that slightly fewer crashes occur in tunnels compared to normal roads, but the fatality rate is substantially higher. Generally the crash risk is higher in the entrance zone of the tunnel than further into the tunnel (Amundsen, 1994; Amundsen and Engelbrektsen, 2009), and the probability of being injured or killed is 19% higher in tunnels with bi-directional traffic compared to tunnels with unidirectional traffic (Robatsch and Nussbaumer, 2004). Nussbaumer (2007) also mentions that according to police reports, the main reasons for tunnel crashes are lacking vigilance (e.g. fatigue,

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