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A psychophysiological and driving performance evaluation of focal and ambient visual processing demands in simulated driving

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ABSTRACT

Research has focused little on the ambient and focal visual channels within which driving and side-task information can be processed. In the current experiment, for the purpose of demonstrating differentiation of focal and ambient visual processing attentional demands on driving performance and physiological response, subjects participated in a dual-task driving simulation that contained focal and ambient components. We hypothesized that ambient demands would not have any effects on driving performance or physiological response, whereas the focal-side-task would cause a deterioration in driving performance and specific changes in physiological response. Support for these hypotheses would provide evidence that focal visual processing is attention demanding, whereas the processing of ambient visual information is not.

Some results suggest that ambient visual information was processed pre-attentively, whereas focal visual information requires attentional resources to be processed. Driving performance deteriorated and changes in physiological response occurred when the focal side-task was added to driving, but not when the ambient side-task was added. However, we failed to see predicted changes in driving performance and physiological response as the demands of the focal and ambient components of the driving simulation varied. The results of the current study suggest that a differentiation in attention demands between focal and ambient vision does exist, but that further research is needed to better understand the nature and practical consequences of the differentiation.

1. Introduction

Driving is a highly visual task in which information is processed from a number of different sources. Some of these sources require the driver to fixate on the information (e.g., reading information presented on the instrument panel, reading text on road signs), while information from other sources can be processed without visual fixation (e.g., side blind zone alerts, perception of velocity through optical flow). Collectively, the processing of information (in addition to tasks like manual control and decision making) makes for an extremely complex control task. In the near future, due to the rapid advances in autonomous vehicles, the driving task is likely to undergo a significant evolution in all aspects, including the visual

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demands imposed upon the driver. Thus, a thorough understanding of current and future visual demand generated through empirical research is important for good in-vehicle technology (IVT) design.

1.1. Insensitivity of driving measures

Past research has illustrated the occasional insensitivity of driving performance measures to changes in the demands of a complex driving task. For example, some research has demonstrated an inability of measures of lateral position to support hypotheses that the use of mobile telephones would lead to increases in lateral deviations (Alm & Nilsson, 1994). Other research has shown that adding a verbal working memory n-back task to a simulated driving task did not significantly affect lateral vehicle control (Lenneman & Backs, 2009). Further, there have been instances in which some driving performance measures do reflect task demands whereas other measures do not (Horrey, Wickens, & Consalus, 2006).

Thus, evidence suggests that the addition of an attention demanding side-task may not affect the performance of maintaining lateral vehicle control, but a driver's ability to respond to hazard events (or other unexpected events) may be impaired (Summala, Nieminen, & Punto, 1996; Summala, Lamble, & Lasko, 1998). One plausible explanation for the dissociation between the effects of a side-task on lateral vehicle control and hazard response is that the two driving components (vehicle control and hazard detection) use information from separate visual channels: focal and ambient vision (Previc, 1998).

1.2. Focal and ambient vision

There is considerable evidence that suggests resources available to process information in focal vision are different than the resources available to process information in ambient vision (Leibowitz & Post, 1982). It has even been suggested that the processing of ambient visual information is pre-attentive, implying that there is no controlled strategic attention mechanism utilized (Previc, 1998; Wickens, 2002). According to Wickens's (2002) multiple resource theory, the resources within the focal-ambient dichotomy are distinct from each other and limited in capacity, and it is competition for shared resources during a divided attention task that will determine the degree of performance degradation from the single-task level. If one or more of the resources are not sufficient to meet desired performance on both tasks, or if one task is emphasized over the other, then performance on at least one of the tasks should decline.

For the purposes of this study, it is important to specifically note the differences between focal and ambient vision. According to Previc (1990), focal vision is very demanding attentionally, relies heavily on the process of foveation, encompasses the central 20–30° of the visual field, is upper field dominant, and is used for complex form perception tasks (e.g., reading, object recognition). Ambient vision encompasses the front 180° of the visual field, is lower field dominant, is used to maintain spatial orientation and postural control during locomotion, and is characterized by the processing of egomotion relevant information. While peripheral and ambient vision are often treated synonymously, they are not two terms for the same concept. Unlike focal vision, which is tightly coupled to the fovea, the egomotion processes that characterize ambient vision can be processed in the foveal region as well as deep into the periphery with very little degradation of detection. Thus, while focal vision is primarily foveal, ambient vision is both foveal and peripheral.

Research suggests that, in general, focal vision is used to maintain longitudinal control (e.g., the distance between your vehicle and the vehicle in front of you) whereas ambient vision is used to maintain lateral vehicle control and detect hazard events. For example, Summala et al. (1996) investigated the effects of the workload imposed by in-vehicle technologies and the use of ambient vision for lane keeping in real-life settings by requiring subjects to drive using peripheral vision. Though subjects were required to focus their visual attention away from the primary driving display, lane keeping performance was maintained well by the subjects. Other studies have shown that driving with peripheral vision or with significant impairments to central visual acuity results in significant degradations in headway maintenance, but lane keeping is unaffected (Lamble, Summala, & Hyvarinen, 2002)

2. Purpose of the study

The first objective was to illustrate the differences in attention demands between focal and ambient vision. The second objective was to test the utility of the autonomic space model, in addition to more traditional cardiac measures, for deciphering psychological-physiological mappings while driving.

2.1. The autonomic space model

The heart is dually-innervated by the sympathetic and parasympathetic branches of the autonomic nervous system (ANS). Sympathetic activation causes an increase in heart rate, whereas parasympathetic activation causes a decrease in heart rate. The "Doctrine of Autonomic Space" posits that ANS activity is multi-dimensionally determined instead of only reciprocally-coupled (Berntson, Cacioppo, & Quigley, 1991; Berntson, Cacioppo, Quigley, & Fabro, 1994). The sympathetic and parasympathetic branches can be reciprocally-coupled (change in heart rate is the result of activation of one branch coupled with withdrawal of the other branch), non-reciprocally-coupled (coactivation or coinhibition), or even uncoupled

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