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Research Report

Attentional demand and processing of relevant visual information during simulated driving: A MEG study

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ABSTRACT

It is a well-known fact that attention is crucial for driving a car. This innovative study aims to assess the impact of attentional workload modulation on cerebral activity during a simulated driving task using magnetoencephalography (MEG). A car simulator equipped with a steering wheel, turn indicators, an accelerator and a brake pedal has been specifically designed to be used with MEG. Attentional demand has been modulated using a radio broadcast. During half of the driving scenarios, subjects could ignore the broadcast (simple task, ST) and during the other half, they had to actively listen to it in order to answer 3 questions (dual task, DT). Evoked magnetic responses were computed in both conditions separately for two visual stimuli of interest: traffic lights (from green to amber) and direction signs (arrows to the right or to the left) shown on boards. The cortical sources of these activities have been estimated using a minimum-norm current estimates modeling technique. Results show the activation of a large distributed network similar in ST and DT and similar for both the traffic lights and the direction signs. This network mainly involves sensory visual areas as well as parietal and frontal regions known to play a role in selective attention and motor areas. The increase of attentional demand affects the neuronal processing of relevant visual information for driving, as early as the perceptual stage. By demonstrating the feasibility of recording MEG activity during an interactive simulated driving task, this study opens new possibilities for investigating issues regarding drivers' activity.

1. Introduction

Despite a continuous decrease in deaths on the French roads during the last ten years, as in other countries, road safety remains a major priority for the government. It is well-known that human errors, whatever their sources, play an important part in car crashes (For example, McEvoy et al., 2006; Stutts et al., 2001; Young et al., 2003). Amongst these sources, atten-

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tional factors play a very important role. Indeed, driving is a complex task which requires sustained and selective attention. Drivers have to constantly adapt their behavior to the changing environment and anticipate future situations. Because of our attentional capacities, only a limited amount of information is processed in-depth at any one time. Therefore, safe and efficient behavior implies that drivers extract and process the most relevant pieces of information according to their objectives and previously-acquired knowledge, redirect their attention when facing novel potentially important events and ignore irrelevant sources of information.

In this context, even minor diversions of attention from the driving task can prove to be disastrous, particularly when a critical situation occurs. A recent American naturalistic study, recording the driving activity of more than 100 drivers for one year (Klauer et al., 2006), reports that, in 78% of all crashes and 65% of near-crashes, the driver was inattentive within the 3 seconds prior to the accident. In this study, driver inattention was induced by sleepiness or drowsiness, as well as secondary tasks or the fact of looking away from the road ahead. However, it can be useful to distinguish issues related to alertness (degree of arousal on the sleep–wake axis) from those related to selective attention since their impact on driver behavior and potential counter-measures can differ considerably. Deficits in selective attention processes are multiple and can occur even when drivers are completely alert. They can be due to dual activities that are voluntary (eating, drinking, phoning, smoking, reading …) or involuntary (being lost in thought, attention attracted by something inside or outside the vehicle, not looking at a relevant source of information) while driving and can induce physical and/or cognitive disruptions. Considering these attention deficits independently from the alertness issue, some epidemiological and naturalistic driving studies estimate that they are a major contributing factor in at least a quarter of all car collisions (Klauer et al., 2006; Stutts et al., 2005). Behavioral studies on simulator and on road have shown that driving performances deteriorate in the case of multitasking behind the wheel (for example, Horberry et al., 2006; Lansdown et al., 2004). Although the deleterious impact of physical activities (manipulating an object) on driving is easily understandable and identifiable, that of cognitive activities is less obvious. However, the use of a cell phone while driving has been shown to increase the risk of accidents, not only due to the physical manipulation it induces but also due to cognitive distraction (Bruyas et al., 2006; Horrey and Wickens, 2006; Strayer et al., 2003; Strayer and Johnston, 2001). In addition, cognitive distraction can occur without mobile phone conversation. Indeed, the increasing presence of assistance and information systems in cars, such as GPS, the possibility of listening to audio-books or the simple fact of thinking about personal issues when driving are only a few examples of activities implying cognitive distraction in a more or less intense way. Therefore, it seems important to gain a better understanding of the impact of cognitive distraction on drivers.

Until now, the impact of attentional defects on driving has mainly been assessed by studying behavioral performances, naturalistic observations or self-reports (Lee, 2008). These approaches can be very informative but they only provide information about the observable or self-reconstructed impact of attentional defects. In order to successfully interact with the environment, sensory data have to be perceived, processed and interpreted to lead to pertinent and observable behavioral responses. Neuroimaging techniques can help to better understand these different steps. They can bring new information to the investigation of specific attentional defects on driving performance by examining the different cerebral stages of information processing.

Electroencephalography and magnetoencephalography (EEG and MEG) are particularly adapted for this purpose. Indeed, the analyses of the event related potentials (ERP) or evoked magnetic fields coming from these techniques enable to characterize the dynamics and spatial distribution of brain activity induced by the perception and the processing of a particular event with an excellent time resolution (fractions of a millisecond) (Luck, 2005). These pieces of information enable to examine the different stages of information processing and allocation of attention. By comparing the brain activity according to the attentional demand of the experimental task, these techniques provide information about when, where and how attention can impact the information processing.

For instance, Garcia-Larrea et al. (2001) have observed the impact of mobile phone use on a simple visual reaction task. Their results show that the increase in attentional demand by phone conversation does not delay target detection times but decreases attentional allocation and interferes with motor preparation processes. Using a more complex task—visual search task, Gherri and Eimer (in press) have also observed an impact of a verbal dual task on ERP components from the perceptual stage. Until now, only a few researchers have used EEG in the more specific domain of driving. Their main purpose was to assess the impact of an increase in attentional demand on the processing of task-relevant information (brake light of the previous car) (Bruyas et al., 2006; Strayer and Drews, 2007) or task irrelevant information (arbitrary sounds in the environment) (Raabe et al., 2005; Rakauskas et al., 2005; Wester et al., 2008). Attentional demand modulation was induced either by a conversation (with a passenger or via a mobile phone) or by the driving task to perform (free driving or following a vehicle). These studies mainly analyzed the characteristics of the ERP component P3. Consistent with Garcia-Larrea et al. (2001), they found a decrease of P3 amplitude following an increase in attentional demand, suggesting a deterioration of the capacity to process task-relevant stimuli. However, their analyses only concerned 3 or 4 sensors and did not allow for an in-depth examination of the spatial distribution of this activity.

Although EEG is easier to use in a driving simulator than the more cumbersome MEG, the latter is more efficient in estimating spatial distributions of the sources owing to the minimal distortion of the signal. In addition, the best signal-to-noise ratio at the level of the sources enables to perform a time-frequency analysis at the level of the sources and an analysis of causality that can shed light on brain functional connectivity. However, MEG is much more expensive and, in the context of driving, implies setting up a car simulator that is adapted to this specific environment. These reasons may explain why it has only been used once in this context. This