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Impact of totally and partially predictive alert in distracted and undistracted subjects: An event related potential study

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ABSTRACT

Rear-end collisions represent about 30% of all car crashes and generate a significant economic cost for society. Driver inattention has been identified as the most important contributing factor in rear-end collisions. One possible countermeasure is the use of systems that warn drivers of potential collisions.

Nevertheless, because of technical constraints, the conception of perfect warning systems is difficult to achieve and technical literature shows that these kinds of systems can be prone to false alerts or misses.

The main objective of this study is to assess the impact of such a warning system on the processing of a relevant driving visual cue while taking into account the reliability of the system and the attentional state of the participants.

For this, we designed a laboratory experiment during which we recorded behavioral data and brain activity (event related potential, ERP) following the detection of a visual target. Three warning conditions were designed: (1) no alert was presented before the visual target; (2) an auditory alert was presented before each target; (3) an alert was presented before the target in 70% of the trials (15% only had the alert without the target, and 15% only had the target without the alert). In addition, participants had to perform this visual detection task either alone (simple task) or with a concurrent problem-solving task (dual task).

Behavioral and electrophysiological data contribute to revealing (1) that there is a behavioral gain induced by the alert and (2) that this gain is at least linked with a time-saving aspect at both the sensory and cognitive stages of neural information processing. Nevertheless, this impact depends on the attentional states of the participant and on the reliability of the alert.

1. Introduction

Driving, although apparently simple because widespread, is a complex task that requires sustained and selective attention. Because the driver evolves in a changing environment, he/she constantly has to adapt his/her behavior to new situations and to anticipate future ones. In order to have a safe and efficient behavior and due to limited attentional capacities, drivers have to extract and process the most relevant pieces of information according to their objectives and previously acquired knowledge of such a situation.

In this context, even minor diversions of attention from the driving task can prove to be disastrous, particularly when a critical situation occurs. In 2006, an 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 s 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.

In order to help drivers in such a situation, numerous advanced warning systems are beginning to be introduced on the car market (Cummings et al., 2007). Because of technical constraints, these kinds of system can be prone to false alarms (false positive) or nuisance alarms (too early) and misses (false negative) (see for example Parasuraman et al., 1997). It is well known that the efficiency and the acceptability of the system depend on these characteristics that should be taken into account for their evaluation.

Among these systems are the forward collision warning systems that aim to alert drivers of potential imminent collisions. Rear-end collisions represent about 30% of all car crashes. They are one of the most common types of collision and represent a significant economic cost for society. It is well known that such systems can impact drivers' behavior in two ways: by faster reaction times and/or by redirecting driver attention to the road if necessary. As driver inattention has been identified as the most important contributing factor of rear-end collisions (Knipling et al., 1993), it is expected that these systems would benefit distracted drivers in

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particular. Nevertheless, the assessment of these systems has not been systematically conducted with distracted drivers (Ben-Yaacov et al., 2002; Bliss and Acton, 2003; Maltz and Shinar, 2004; Abe and Richardson, 2006) and when it is the case, studies show different results depending on which kind of warning and/or secondary task is used. For example, Mohebbi et al. (2009) found that the addition of a simple conversation (demographic and personal questions) did not reduce the effectiveness of a tactile warning compared with an auditory warning. When the complexity of the conversation increases (mental calculation and categorization questions), the effectiveness of the tactile warning is reduced, however still being more helpful than the auditory warning which is not significantly different from no warning at all. Nevertheless, Ho and Spence (2009) found more benefit from an auditory alert than from a vibrotactile one. They studied the effectiveness of different warnings when participants performed a secondary task in which they had to look forward or away. As expected, results showed that the percentage of errors significantly increased when the warning was absent and participants were looking away. In addition, they observed faster reaction times for the auditory warning presented close to participants, than when it was presented further away, the less efficient being the vibrotactile warning. Lee et al. (2002) compared the benefit of the (auditory and visual) warning for both distracted and undistracted drivers. Their results showed a large safety benefit of the alert in both groups.

Four major types of driver distraction are usually distinguished: visual, auditory, physical and cognitive (Pettitt et al., 2005). In the framework of this project, we have focused our research on drivers' cognitive distraction. We consider cognitive distraction as the endogenous orienting of attention on thoughts. Thoughts are essentially internal to the driver and not directly observable. Therefore, this kind of distraction is the most difficult to apprehend. In addition, cognitive activity may be highly engaging, which can cause serious implications for safety (Horrey et al., 2009).

Until now, the impact of attentional load modifications during various driving situations has been analyzed by studying observable parameters directly (behavior and performances) and declarative data (for example Ben-Yaacov et al., 2002; Wiese and Lee, 2004; Abe and Richardson, 2006). In order to have a better understanding of the mechanisms underlying drivers' attentional processes and the genesis of their failures, it is advisable to use other types of parameters that enable to distinguish between the various stages of information processing and identify, in this chain, the weakest link likely to be responsible for these failures.

In order to reach these objectives, neuroimaging technologies with good temporal resolution, such as electroencephalography (EEG) and associated event related potential (ERP) technique, have been used. Indeed, this technique enables to make a distinction between the perceptive and the cognitive stages of information processing. The sequence of ERP components following a stimulus reflects the sequence of neural processes triggered by the stimulus, beginning with early sensory processes and proceeding through decision- and response-related processes (for review see Luck et al., 2000). ERP components are classically defined by a letter (N or P) corresponding to the polarity of the component (negative or positive) and a number corresponding to its position in the chronology (i.e. P1, N1, N2, P2, P3) or the classical latency of the peak (i.e. N185 corresponds to a negative component peaking around 185 ms following the stimulus of interest). Classically, the early ERP components (those that appear earlier than 200 ms after the presentation of the elicited stimulus) such as P1 and N1 have been mainly linked to sensory processes as well as to the discriminative processing and are modulated by physical attributes of the stimuli. The late ERP components such as N2 and P3 have been thought to reflect higher cognitive processes (stimulus evaluation or categorization and decision-making) and can be used as a measure of resource allocation (see for example Picton, 1992; Hillyard and Anllo-Vento, 1998; Luck, 2005).

In this experiment, in order to estimate the impact of a warning signal, reaction time (RT) to a visual target was measured, and ERP components linked to sensory visual processes (visual N1) and to higher cognitive processes (N2/P3) were examined, taking into account the attentional state of the subjects as well as the reliability of the system.

2. Materials and methods

2.1. Participants

12 right-handed adults (6 men) aged from 22 to 40 years old (mean age: 25.4) took part in this experiment. None suffered from neurological disorders and all had normal or corrected-to-normal sight and normal hearing. They were all native French speakers, had held a driving license for at least 3 years and declared that they drove at least 3000 km per year. Written informed consent was obtained from each subject and they received payment for their participation. The research protocol was approved by INRETS (now IFSTTAR) and the French national research ethics committee (Declaration of Helsinki).

2.2. Stimuli and procedure

Participants completed a simple visual detection task. Stimuli were presented on a computer screen placed 1 m from the subject. They consisted of a dull red disc at the middle of the screen appearing on a gray background. This disc grew and diminished continuously and randomly. This movie was realized using a succession of images presented for 80 ms or 160 ms. 5 images representing 5 different sizes of the disc were used. The 5 sizes of the disc corresponded to a visual angle of 0.2° for the shortest one, 0.4°, 0.6°, 0.8° and 1° for the biggest one. The succession of the images always kept the gradual order (e.g. the disc of 0.4° could be followed either by the 0.2° or the 0.6° disc but never by the 0.8° or 1° disc). When reaching its maximum size, in 33% of the cases the red disc got brighter for 240 ms, for the other 67%, the red disc stayed dull. Subjects had to remove their right foot from a pedal as fast as possible in response to the bright red disc which constituted the visual target. The delay between two trials varied randomly from 2880 to 6720 ms (mean 4800 ms).

Three experimental conditions were designed and presented in separate blocks. In the no system condition (NS), no warning was given before the visual target. In the perfect system condition (PS), the visual target was always preceded by an auditory alert. This alert consisted of a 750 Hz tone burst lasting for 400 ms and was presented from 1100 to 2000 ms (mean 1550 ms) before the target simulating a forward collision warning system. In the imperfect system condition (IS), the auditory alert was presented before the visual target in 70% of all the trials. In 15% of the trials, the alert was presented but no visual target followed and in the other 15% the visual target appeared alone without any alert. Whatever the condition, participants were instructed to wait for the visual target before removing their foot from the pedal.

Subjects performed this task in two separate sessions. In one session, they had to perform the visual detection task only (simple task condition, ST) while in the other session they had to perform the visual detection task as well as a secondary cognitive task (dual task condition, DT). The secondary task consisted in a problem-solving task that we called the Mystery Word inspired by the remote associate test described by Mednick (1962). In this task, a set of 3 words with apparently no links between them was given orally to the participants who had to find a fourth word linked to each of the