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Attention and driving performance modulations due to anger state: Contribution of electroencephalographic data

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Abstract:

Driver internal state, including emotion, can have negative impacts on road safety. Studies have shown that an anger state can provoke aggressive behavior and impair driving performance. Apart from driving, anger can also influence attentional processing and increase the benefits taken from auditory alerts. However, to our knowledge, no prior event-related potentials study assesses this impact on attention during simulated driving. Therefore, the aim of this study was to investigate the impact of anger on attentional processing and its consequences on driving performance. For this purpose, 33 participants completed a simulated driving scenario once in an anger state and once during a control session. Results indicated that anger impacted driving performance and attention, provoking an increase in lateral variations while reducing the amplitude of the visual N1 peak. The observed effects were discussed as a result of high arousal and mind-wandering associated with anger. This kind of physiological data may be used to monitor a driver's internal state and provide specific assistance corresponding to their current needs.

Keywords: Anger; Event-Related Potentials; Visual N1; Lateral variations; Car simulator; Attention

Introduction

Anger, which is a negative and highly arousing emotion, is commonly experienced while driving [1]. A consequence of experiencing this emotional state can be outward expression of aggression through verbal or behavioral means [2]. Such expression can include the use of one's vehicle to show own frustration to other road users or to frustrate another driver [3]. Furthermore, studies have linked driving anger to traffic rules infringements [4,5], a reduction of lateral control [6], and a reduction of following distances [7]. One frequently reported effect of driving anger is its ability to modulate driving style, leading to higher driving speeds and stronger accelerations [5,6,8].

The impact of anger on driving performance involves more than just behavioral modifications. Several negative effects also occur at a cognitive level, including the tendency to use a heuristic processing style, making drivers rely on superficial cues rather than on the significance of stimuli and leaving drivers unlikely to carefully analyze their environments [9]. For example, increased driving speeds caused by anger seem to be predominantly mediated by a situational awareness deficit [8]. Angry drivers are less likely to be aware of critical information or potential hazards on the road.

Although a number of studies have investigated the impacts of anger state on driving behavior, its impact on attentional processing while driving has rarely been studied. Basic research studies assessing the efficiency of attentional processing have revealed that emotions could improve the most basic perceptual abilities [10]. Concerning anger, Techer et al. [11], used the Attention Network Test – Interactions (ANT-I) [12] to investigate the impact of anger on attention. The ANT-I is a modified version of the Attention Network Test (ANT) [13] that can be used to study the influence of several contexts on attentional processing of neutral stimuli. This test, based on the model of attentional networks [14], allows the evaluation of the three attention sub-systems: the alerting, the orienting and the executive control networks. Techer et al. [11] found a positive impact of anger on the alerting network, probably attributable to its high level of arousal.

Such effect on attention may also be observed using physiological measures such as Event Related Potentials (ERP). This electrophysiological technique is based on the observation of averaged brain electrical signals after a repeated stimulus presentation so as to infer on the underlying cognitive processes [15]. According to ERP literature, the first negative electrical peak after stimulus onset (N1) mainly reflects the perceptual processing stage of a target

[15,16]. The amplitude of this component seems partly linked to the quantity of attentional resources allocated to sensorial processing. Additionally, this component is also sensible to the task. Its amplitude and latency are higher during a discrimination task than during a simple detection task [16,17]. For its part, the positive P3 peak is thought to inform on the cognitive processing of information and the inhibition of non-pertinent stimuli or responses [15,18]. During the ANT, both alerting and orienting signals could impact N1 amplitude [19], the largest amplitude being elicited during trials with alerting and orienting cues. As for P3, changes in amplitude were observed when target stimulus was flanked by incongruent stimuli, suggesting an effect of the executive control network [19]. Thus, changes in the efficiency of one attentional network may be observed with ERP measures.

Modulations of ERP amplitudes can also be observed during emotional information processing. Literature suggests that the valence dimension of a stimulus seems to affect preferentially early components [20,21]. For example, unpleasant picture processing can lead to larger P1 amplitude when compared with pleasant picture processing. As for late components, their amplitude can increase when processing highly arousing stimuli [20]. The effects on ERPs provoked by stimulus arousal are also observed during neutral information processing according to individual's arousal level [18]. It has been interpreted as an arousal-related modulation in the quantity of available attentional resources. Therefore, in a driving context, physiological arousal and negative valence evoked by an angry mood may impact the electrophysiological response of drivers.

To our knowledge, no study has ever measured the impact of an anger state on ERPs while driving. Additionally, the relationship between anger and the alerting network [11] is of particular interest due to the relative importance of this network during driving. Alerting signals are common and represent critical information for driving safety. Thus, a more efficient alerting network would allow the driver to take a greater advantage of the numerous alerting signals. However, ERP technique is particularly sensitive to motor activation, which may be a limitation to its usability in a driving context. For that reason, Bueno et al. [22] developed a simulated driving task (consisting in a motorcycle following paradigm, on a straight rural road) compatible with ERPs collection. It successfully revealed several effects of a forward collision alerting system as well as cognitive distraction on ERPs. [22]. Thus, the use of this ADAS reduced P3 latency evoked by the motorcycle's braking lights.

The aim of this present study was to investigate the impact of an anger state on attention while driving, using the ERP technique, and its impact on driving. Anger was expected to influence

ERPs following auditory alert and braking light of the leading motorcycle due to increased arousal level and the greater efficiency of the alerting network. Such effect would imply an increase of auditory N1, and visual N1 and P3 amplitudes. Additionally, anger was expected to disrupt driving performance as measured by reaction times, control of speed and lateral position.

Participants

Thirty-three participants (19 females) aged between 25 and 40 (*M* = 32.3; *SD* = 5.5) were involved in this study and received a financial compensation. They reported a normal or corrected to normal vision, no neurologic disease and no medical treatment. Every participant was right-handed and had more than three years of driving experience. The research protocol was carried out in accordance with The Code of Ethics of the World Medical Association.

Material

Mood induction and measurement

Two experimental sessions were used. In the Anger session, participants were induced using the autobiographical recall procedure [23]. They had ten minutes to recall and write down a personal event during which they experienced anger, and were encouraged to provide as many details as they could. In the Control session, participants were not induced. In order to keep their natural mood, they had ten minutes to complete questionnaires about their driving habits. Mood states were measured using a modified version of the Brief Mood Introspection Scale (BMIS) [24]. The BMIS is a 16-item self-report questionnaire in which each adjective refers either to anger, happiness, sadness or calmness. It is rated on a 7-point scale, ranging from “not at all” to “absolutely”, providing a score for the valence and the arousal dimensions of the emotional state.

Apparatus

The experimental scenario was presented to participants in a driving simulator composed of a 24” screen, an adjustable car seat, a steering wheel and three pedals.

Electroencephalographic data was collected using the Biosemi ActiveTwo system® sampled at 1024Hz. Electrodes were placed on an electrode cap which was organized according to the international 10-20 system. Two mastoids electrodes were also placed on Ma1 and Ma2, and one EOG electrode was placed near the right eye. The reference electrode was placed on the nose. Event related potentials were extracted offline using the ELAN software [25].

Procedure

Each participant completed an Anger and a Control experimental session with a weekly interval. The session order was counterbalanced between the participants. Each session followed the same structure. After completing the informed consent form, the EEG recording apparatus was set on participants. They were seated in the simplified driving simulator at 90cm eye-screen distance and completed a 13.5-minute training scenario based on the procedure of Bueno et al. [22], in which they were instructed to follow a motorcycle. The driving task was designed to require a low level of motor activation so as to improve the quality of ERP collection. Participants drove on a straight rural road with no crosswinds and no regular steering was needed. A speed limiter ensured that participants drove at a consistent speed. They were instructed to maintain the accelerator pedal pushed as long as the motorcycle did not brake.

Every time they saw the brake lights of the motorcycle, they had to release the accelerator pedal as quickly as they could. They were also asked to adjust their pace in order to keep a safe distance to the lead vehicle. When participants reached the 70km/h speed limit, the first of the 90 trials started. Each trial started by a random duration comprised between 400 and 1600ms. In 80 of the 90 trials, a 500ms alerting auditory signal indicated to the participant that the lead vehicle would brake imminently. In the 10 remaining trials, no alerting signal was displayed. After 500ms, the motorcycle braked for a duration of 2 seconds, decelerating from 70km/h to 35km/h. In 15 of those trials, the deceleration of the lead vehicle was more important, shifting from 70 km/h to 10 km/h, so as to break the monotony of the task and prevent the driver from losing concentration. The brake lights of the motorcycle were lit throughout the 2000ms corresponding to the braking maneuver. At the end of the trial, the motorcycle accelerated to get back to the initial inter-vehicular distance and participants had to push the accelerator pedal at its maximum again. Between trials, the motorcycle was programmed to keep a distance corresponding to 2 seconds at a 70km/h speed so as to reproduce exactly the same driving conditions for each trial. The next trial started immediately. This trial structure ensured that each participant was placed in a comparable situation with one motorcycle braking on average every nine seconds. To counter the high braking predictability, the random time implemented at the beginning of each trial made the interval between two targets irregular, ranging from 7.8 seconds to 10.2 seconds. After the training scenario and before the Mood Induction Procedure (MIP), participants had to fill in the first BMIS questionnaire (Moment 1), then followed the MIP corresponding to the current session. Finally, after the MIP, they had to fill in the second

BMIS (Moment 2) followed by the experimental scenario which was identical to the training scenario.

Analyses

Event-related potentials

Auditory and visual ERPs were computed for trials with auditory alert. They were filtered offline at 1Hz – 30Hz, computed on a time window from -200ms to 800ms and baselined from 200ms to 0ms pre-stimulus window. Each ERP component was analyzed at the traditional locations observed in the literature [15].Auditory N1 analyzed windows ranged from 80ms to 160ms after auditory alert onset at Cz, FC1, FC2 and Fz. Visual N1 window was set from 160ms to 230ms after the braking lights onset and was analyzed on IMA, IMB, P7, P8, PO3, PO4, O1 and O2 sites. Finally, P3 was recorded during the 250ms to 400ms window for Pz, P3, P4, PO3, PO4, O1 and O2 electrode sites.

All ERP analysis were conducted using ELAN software and ERP waves visualization was conducted using ERPA software [25]. For each component, according to its polarity, the most negative or positive value on each electrode site was recorded. Those values were then averaged between electrodes to obtain the maximum or minimum ERP component amplitude. The latencies of negative or positive peaks were recorded and averaged between electrodes to obtain the latency of the ERP component. Considering the little number of trials without auditory alert, these trials were not included in the analyses and were not compared to cued trials. Thereby the analysis was not on the impact of anger on the alerting effect, but rather on its impact on an alerting cue processing during driving.

Driving performance

Several driving indicators were recorded to analyze driving performance. Response times were calculated as the duration between braking lights onset and participants’ reaction. Number of anticipations was also recorded as the number of trials for which participants reacted before the braking lights. Finally, intervehicular distance and standard deviation of lateral position (SDLP) in meters were recorded to give an indication of longitudinal and lateral control of participants.

Results

Mood measurement

The emotional state was assessed before and after the MIP of each session. A repeated measure ANOVA was carried out with the Session (Anger/Control) and the Moment

(Moment 1/Moment_2) as within-subject factors, on the mean anger ratings or the mean arousal ratings as dependent variables.

The mean anger ratings analysis revealed a main effect of the Session ($F(1, 32) = 11.08$, $p < .001$, $\eta^2 = .258$) and a main effect of the Moment ($F(2, 64) = 25.08$, $p < .001$, $\eta^2 = .439$). A significant Session × Moment interaction was also found ($F(2, 64) = 20.07$, $p < 001$, $\eta^2 = .385$). Planned comparisons revealed no difference before induction ($F(1, 32) < 1$, *n.s.*, $\eta^2 = .002$). At Moment 2, a significant difference was found ($F(1, 32) = 14.75$, $p < .001$, $\eta^2 = 0.357$) with a higher anger rating after induction during the Anger session ($M = 2.11$, $SD = 1.22$) than during the Control session ($M = 1.18$, $SD = 0.39$).

Similar effects were observed for the mean arousal ratings. The analysis revealed a main effect of the Session ($F(1, 32) = 10.81$, $p < .01$, $\eta^2 = .252$) and a main effect of the Moment ($F(2, 64) = 17.22$, $p < .001$, $\eta^2 = .350$). A significant Session × Moment interaction was also found ($F(2, 64) = 6.28$, $p < .01$, $\eta^2 = .164$). Planned comparisons revealed no difference in Moment 1 ($F(1, 32) = 3.62$, *n.s.*, $\eta^2 = 0.102$). After induction, a significant difference was found ($F(1, 32) = 16.28$, $p < .001$, $\eta^2 = .384$) with a higher arousal rating in Moment 2 during the Anger session ($M = 4.10$, $SD = 0.39$) than during the Control session ($M = 3.80$, $SD = 0.32$).

Table 1

Anger and Arousal mean ratings (SD) before and after induction according to the session

	Anger ratings		Arousal ratings	
	Moment 1	Moment 2	Moment 1	Moment 2
Anger	1.10 (*0.22*)	2.11 (*1.22*)	3.84 (*0.27*)	4.10 (*0.39*)
Control	1.09 (*0.25*)	1.18 (*0.39*)	3.71 (*0.37*)	3.80 (*0.32*)

Driving performance

A one-way ANOVA with repeated measures was carried out with the Session (Anger/Control) as a within-subject factor, on the driving performance indicators (Response times, inter vehicular distance, standard deviation of lateral position and number of anticipations). The analyses only revealed a significant effect of the Session on SDLP ($F(1, 32) = 4.41$, $p < 05$,

$\eta^2 = 0.121$) with higher SDLP during Anger session (*M* = 0.351, *SD* = 0.09) compared to the Control session (*M* = 0.324, *SD* = 0.11).

Event-related Potentials

Due to insufficient data quality for 9 participants, ERPs analyses were carried out on 24 participants. The impact of mood on auditory N1, visual N1 and P3 latencies and amplitudes were tested by repeated measures one-way ANOVAs with Session (Control/Anger) as a within-subject factor. Analyses revealed no significant effect of Session on auditory N1 and P3.

No significant result was revealed by the analysis concerning visual N1 latency. However, analyses revealed a significant effect of Session on visual N1 amplitude ($F(1, 23) = 5.43$, $p < 05$, $\eta^2 = .191$) which was smaller during Anger session than in Control session (Table 2).

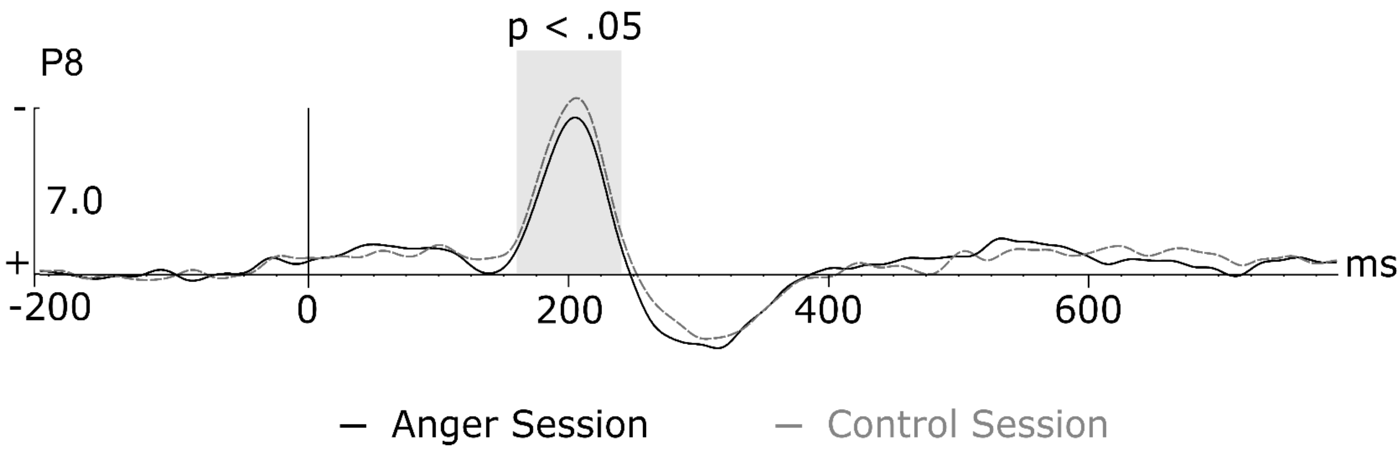

Figure 1: Grand average of the visual ERP on electrode P8 according to the session

Table 2

ERP mean amplitudes and latencies for each measured ERP component according to the session (=p<.05)*

		Visual N1		P3		Auditory N1	
		M	*SD*	M	*SD*	M	*SD*
Amplitude							
Anger session	*	-7,16	*3,67*	6,27	*3,31*	-9,02	*4,52*
Control session		-8,21	*3,73*	5,29	*3,02*	-9,51	*5,79*
Latency							
Anger session		202,29	*19,32*	306,95	*41,02*	119,20	*14,08*
Control session		203,61	*16,95*	307,03	*33,27*	123,89	*15,33*

Discussion

This study assessed the influence of an anger state on attentional processing while driving, as measured by Event Related Potentials (ERPs) and its impact on driving performance. Anger was expected to influence attentional processes as a result of high levels of arousal and the alerting network efficiency associated therewith [11]. Additionally, anger was expected to alter driving performance by disrupting reaction times as well as control of speed and lateral position.

First of all, it can be noted that N1s latencies are quite late as in the Bueno’s studies [22] compared to basic studies. This may be due to our dynamic environment associated to low salience of stimuli because of the auditory and visual context within the car simulator. Further research will be necessary to test this hypothesis.

Concerning the induction, results confirm that the MIP was efficient to induce participants in anger since after the MIP, participants reported higher anger and arousal ratings.

However, ERP data did not support our initial hypothesis concerning an increase of the auditory N1, and visual N1 and P3 amplitudes. On the contrary, during the anger session, the amplitude of visual N1 was smaller than in the control session.

The generation of mind wandering (MW) could explain this unexpected result. MW is a reorientation of the attention to internal thoughts not linked to the driving task [26]. According to the literature, a N1 amplitude reduction could be linked with a perceptual decoupling during MW episodes [26–28]. A strong bidirectional relationship exists between negative emotions and MW [26,29]. On the one hand, a negative mood can lead to MW [29] and thinking about negative life events can be used to induce a negative emotional state [23]. On the other hand, the emergence of MW can also depend on the task. Normally, it appears foremost when a task is highly repetitive and monotonous [30], which corresponds to the protocol of the current study. Therefore, it is possible that our monotonous task associated to the autobiographical induction procedure had generated MW. A reduction of the visual N1 amplitude may indicate a reduction of the attention allocated to the sensorial processing of braking lights through an attenuation of sensorial sensitivity [27]. Moreover, the procedure used here was previously developed to show an impact of cognitive distraction on ERPs [22]. These authors observed that a cognitive distraction reduced the visual N1 and P3 amplitudes. However, our participants were not asked to be engaged in a cognitive distraction task and as a result of the fog used in the driving environment, only stimuli used for the following task were displayed on the simulator screen. Therefore, our results seem to be consistent with the idea that drivers were distracted due to their attention being allocated towards internal thoughts.

The presence of MW could also give another point of view to the fact that induced anger in the present experiment did not show the expected effect on the alerting network as observed by Techer et al. [11] using the ANT-I. This task requires a continuous attentional focus which could not be suitable for the generation of MW. On the contrary, as mentioned above, the driving task used in the present study was monotonous and favorable to MW which could be responsible for the reduced amplitude of visual N1 and for minimizing or suppressing the alerting effect.

The N1 effect may reflect a lack of sensitivity to stimuli present in the environment [27]. Therefore, angry drivers may process critical information in a more superficial way which is consistent with a reactivity reduction in case of unexpected hazards [31].

Concerning the expected effects on driving performance, we observed no effect of anger on response times and speed control. It may be a direct consequence of the highly controlled situation in which participants were placed, reducing the possible sources of variability. However, analyses revealed that participants had a degraded lateral control of their vehicle during the anger session, as indicated by the increased standard deviation of lateral position (SDLP). Such increase in variations of lane positioning was previously observed for drivers induced in anger by the driving situation [5]. It seems also consistent with the literature stating that angry driving could lead to higher lateral accelerations [6]. In both of these studies, it was interpreted to be a result of drivers engaging in aggressive behaviors to avoid being impeded. However, in our study, the lead motorcycle was not impeding and drivers were instructed to follow it. Moreover, no active steering was required to complete the driving task. Therefore, the increased variations in lateral position may be a reflection of changes occurring at an attentional level. As previously mentioned, ERP data suggested that drivers' attention was impacted by anger in a comparable way to mind-wandering. However, previous studies using comparable driving conditions seem to indicate that drivers involved in distractive tasks or in MW episodes tend to have a reduced SDLP [32,33]. SDLP is also observed with an increase of cognitive workload [34]. It may indicate that drivers prioritized other driving sub-tasks more demanding than lateral control [34]. Thus, the increased SDLP observed here does not seem to be induced by MW. Then, the other possible explanation could be linked to the high levels of arousal which defines anger. As stated by Logan and Crump [35], when a conscious monitoring of a low-demanding task is possible, the performance obtained for this task can be disrupted. Thus, if arousal can rise the amount of available attentional resources [36], the participants in the anger session may have allocated attention to their internal thoughts for one part and to a conscious monitoring of the vehicle lateral control for another part. This last can explain the increased variation of lateral position provoked by anger. However, Ünal et al. [37] asked to their participants to listen to music of their choice while performing the same car following task. They observed that a high level of arousal could reduce the standard deviation of lateral position [37]. This effect was found with a musical playlist set up by the participants. Unfortunately Ünal et al. [37] did not asses the valence dimension in their study. This issue raises the question about the role of valence. Thus, future research should take into account this dimension so as to disentangle the effects of moods defined by a similar level of arousal on lateral variations.

Considering the electrophysiological and behavioral results, the effects of anger observed here may not be explained only by the presence of MW episodes or high levels of arousal, but from a combination of these two factors: one having an effect on the sensory processing and the other one on the attentional resources management revealed by the lateral control of the vehicle. Consequently, to identify the effects of a such emotion, several indicators have to be taken into account. Previous studies revealed that perceptual decoupling from visual stimuli is not a continuous phenomenon [27]. That is why drivers may constantly switch between a physiological activity corresponding to aroused states and a perceptual decoupling corresponding to MW. Further research on this topic is needed to better understand the influence of anger which may have a more complex impact on ERPs than expected.

In any case, the results obtained from the present study open new investigation opportunities regarding the impact of emotional states on attention during a driving task. Future studies may focus on the effects of other emotional states in different driving tasks. As an ultimate goal, those results may be used in the design of future driving assistance systems in order to provide support corresponding to drivers' current internal state.

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