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# 1 Attention and driving performance modulations due to anger state: 2 Contribution of electroencephalographic data

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24 Abstract:

25 Driver internal state, including emotion, can have negative impacts on road safety. Studies  
26 have shown that an anger state can provoke aggressive behavior and impair driving  
27 performance. Apart from driving, anger can also influence attentional processing and increase  
28 the benefits taken from auditory alerts. However, to our knowledge, no prior event-related  
29 potentials study assesses this impact on attention during simulated driving. Therefore, the aim  
30 of this study was to investigate the impact of anger on attentional processing and its  
31 consequences on driving performance. For this purpose, 33 participants completed a simulated  
32 driving scenario once in an anger state and once during a control session. Results indicated that  
33 anger impacted driving performance and attention, provoking an increase in lateral variations

34 while reducing the amplitude of the visual N1 peak. The observed effects were discussed as a  
35 result of high arousal and mind-wandering associated with anger. This kind of physiological  
36 data may be used to monitor a driver's internal state and provide specific assistance  
37 corresponding to their current needs.

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

40

41

## 42 Introduction

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

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

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

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

74 [15,16]. The amplitude of this component seems partly linked to the quantity of attentional  
75 resources allocated to sensorial processing. Additionally, this component is also sensible to the  
76 task. Its amplitude and latency are higher during a discrimination task than during a simple  
77 detection task [16,17]. For its part, the positive P3 peak is thought to inform on the cognitive  
78 processing of information and the inhibition of non-pertinent stimuli or responses [15,18].  
79 During the ANT, both alerting and orienting signals could impact N1 amplitude [19], the largest  
80 amplitude being elicited during trials with alerting and orienting cues. As for P3, changes in  
81 amplitude were observed when target stimulus was flanked by incongruent stimuli, suggesting  
82 an effect of the executive control network [19]. Thus, changes in the efficiency of one  
83 attentional network may be observed with ERP measures.

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

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

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

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

## 112 *Participants*

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

## 118 *Material*

### 119 *Mood induction and measurement*

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

### 130 *Apparatus*

131 The experimental scenario was presented to participants in a driving simulator composed of a  
132 24” screen, an adjustable car seat, a steering wheel and three pedals.

133 Electroencephalographic data was collected using the Biosemi ActiveTwo system® sampled at  
134 1024Hz. Electrodes were placed on an electrode cap which was organized according to the  
135 international 10-20 system. Two mastoids electrodes were also placed on Ma1 and Ma2, and  
136 one EOG electrode was placed near the right eye. The reference electrode was placed on the  
137 nose. Event related potentials were extracted offline using the ELAN software [25].

138

### 139 Procedure

140 Each participant completed an Anger and a Control experimental session with a weekly interval.  
141 The session order was counterbalanced between the participants. Each session followed the  
142 same structure. After completing the informed consent form, the EEG recording apparatus was  
143 set on participants. They were seated in the simplified driving simulator at 90cm eye-screen  
144 distance and completed a 13.5-minute training scenario based on the procedure of Bueno et al.  
145 [22], in which they were instructed to follow a motorcycle. The driving task was designed to  
146 require a low level of motor activation so as to improve the quality of ERP collection.  
147 Participants drove on a straight rural road with no crosswinds and no regular steering was  
148 needed. A speed limiter ensured that participants drove at a consistent speed. They were  
149 instructed to maintain the accelerator pedal pushed as long as the motorcycle did not brake.

150 Every time they saw the brake lights of the motorcycle, they had to release the accelerator pedal  
151 as quickly as they could. They were also asked to adjust their pace in order to keep a safe  
152 distance to the lead vehicle. When participants reached the 70km/h speed limit, the first of the  
153 90 trials started. Each trial started by a random duration comprised between 400 and 1600ms.  
154 In 80 of the 90 trials, a 500ms alerting auditory signal indicated to the participant that the lead  
155 vehicle would brake imminently. In the 10 remaining trials, no alerting signal was displayed.  
156 After 500ms, the motorcycle braked for a duration of 2 seconds, decelerating from 70km/h to  
157 35km/h. In 15 of those trials, the deceleration of the lead vehicle was more important, shifting  
158 from 70 km/h to 10 km/h, so as to break the monotony of the task and prevent the driver from  
159 losing concentration. The brake lights of the motorcycle were lit throughout the 2000ms  
160 corresponding to the braking maneuver. At the end of the trial, the motorcycle accelerated to  
161 get back to the initial inter-vehicular distance and participants had to push the accelerator pedal  
162 at its maximum again. Between trials, the motorcycle was programmed to keep a distance  
163 corresponding to 2 seconds at a 70km/h speed so as to reproduce exactly the same driving  
164 conditions for each trial. The next trial started immediately. This trial structure ensured that  
165 each participant was placed in a comparable situation with one motorcycle braking on average  
166 every nine seconds. To counter the high braking predictability, the random time implemented  
167 at the beginning of each trial made the interval between two targets irregular, ranging from 7.8  
168 seconds to 10.2 seconds. After the training scenario and before the Mood Induction Procedure  
169 (MIP), participants had to fill in the first BMIS questionnaire (Moment 1), then followed the  
170 MIP corresponding to the current session. Finally, after the MIP, they had to fill in the second

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

## 173 Analyses

### 174 Event-related potentials

175 Auditory and visual ERPs were computed for trials with auditory alert. They were filtered  
176 offline at 1Hz – 30Hz, computed on a time window from -200ms to 800ms and baselined from  
177 200ms to 0ms pre-stimulus window. Each ERP component was analyzed at the traditional  
178 locations observed in the literature [15]. Auditory N1 analyzed windows ranged from 80ms to  
179 160ms after auditory alert onset at Cz, FC1, FC2 and Fz. Visual N1 window was set from 160ms  
180 to 230ms after the braking lights onset and was analyzed on IMA, IMB, P7, P8, PO3, PO4, O1  
181 and O2 sites. Finally, P3 was recorded during the 250ms to 400ms window for Pz, P3, P4, PO3,  
182 PO4, O1 and O2 electrode sites.

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

### 192 Driving performance

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

## 198 Results

### 199 Mood measurement

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



202 (Moment 1/Moment\_2) as within-subject factors, on the mean anger ratings or the mean arousal  
 203 ratings as dependent variables.

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

211 Similar effects were observed for the mean arousal ratings. The analysis revealed a main effect  
 212 of the Session ( $F(1, 32) = 10.81$ ,  $p < .01$ ,  $\eta^2 = .252$ ) and a main effect of the Moment ( $F(2,$   
 213  $64) = 17.22$ ,  $p < .001$ ,  $\eta^2 = .350$ ). A significant Session  $\times$  Moment interaction was also found  
 214 ( $F(2, 64) = 6.28$ ,  $p < .01$ ,  $\eta^2 = .164$ ). Planned comparisons revealed no difference in Moment  
 215 1 ( $F(1, 32) = 3.62$ ,  $n.s.$ ,  $\eta^2 = 0.102$ ). After induction, a significant difference was found ( $F(1,$   
 216  $32) = 16.28$ ,  $p < .001$ ,  $\eta^2 = .384$ ) with a higher arousal rating in Moment 2 during the Anger  
 217 session ( $M = 4.10$ ,  $SD = 0.39$ ) than during the Control session ( $M = 3.80$ ,  $SD = 0.32$ ).

218 Table 1

219  
 220 *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)

221

## 222 Driving performance

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

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

#### 229 Event-related Potentials

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

234 No significant result was revealed by the analysis concerning visual N1 latency. However,  
235 analyses revealed a significant effect of Session on visual N1 amplitude ( $F(1, 23) = 5.43$ ,  
236  $p < 0.05$ ,  $\eta^2 = .191$ ) which was smaller during Anger session than in Control session (Table 2).

237

238

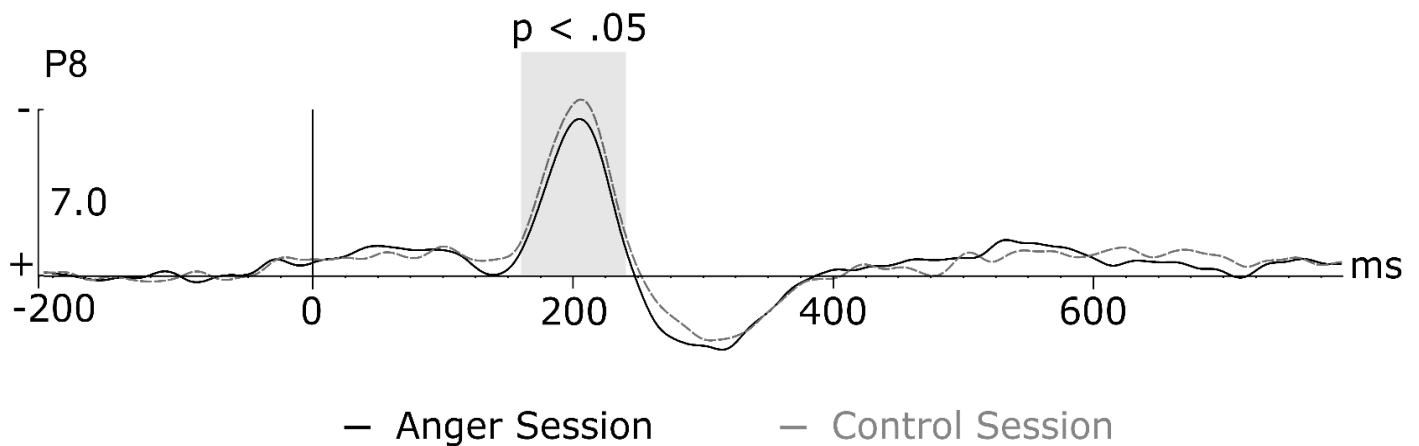


Figure 1: Grand average of the visual ERP on electrode P8 according to the session

239  
240  
241

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
<b>Amplitude</b>						
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
<b>Latency</b>						
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

242

## 243 Discussion

244 This study assessed the influence of an anger state on attentional processing while driving, as  
245 measured by Event Related Potentials (ERPs) and its impact on driving performance. Anger  
246 was expected to influence attentional processes as a result of high levels of arousal and the

247 alerting network efficiency associated therewith [11]. Additionally, anger was expected to alter  
248 driving performance by disrupting reaction times as well as control of speed and lateral position.

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

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

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

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

276 The presence of MW could also give another point of view to the fact that induced anger in the  
277 present experiment did not show the expected effect on the alerting network as observed by  
278 Techer et al. [11] using the ANT-I. This task requires a continuous attentional focus which

279 could not be suitable for the generation of MW. On the contrary, as mentioned above, the  
280 driving task used in the present study was monotonous and favorable to MW which could be  
281 responsible for the reduced amplitude of visual N1 and for minimizing or suppressing the  
282 alerting effect.

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

286 Concerning the expected effects on driving performance, we observed no effect of anger on  
287 response times and speed control. It may be a direct consequence of the highly controlled  
288 situation in which participants were placed, reducing the possible sources of variability.  
289 However, analyses revealed that participants had a degraded lateral control of their vehicle  
290 during the anger session, as indicated by the increased standard deviation of lateral position  
291 (SDLP). Such increase in variations of lane positioning was previously observed for drivers  
292 induced in anger by the driving situation [5]. It seems also consistent with the literature stating  
293 that angry driving could lead to higher lateral accelerations [6]. In both of these studies, it was  
294 interpreted to be a result of drivers engaging in aggressive behaviors to avoid being impeded.  
295 However, in our study, the lead motorcycle was not impeding and drivers were instructed to  
296 follow it. Moreover, no active steering was required to complete the driving task. Therefore,  
297 the increased variations in lateral position may be a reflection of changes occurring at an  
298 attentional level. As previously mentioned, ERP data suggested that drivers' attention was  
299 impacted by anger in a comparable way to mind-wandering. However, previous studies using  
300 comparable driving conditions seem to indicate that drivers involved in distractive tasks or in  
301 MW episodes tend to have a reduced SDLP [32,33]. SDLP is also observed with an increase of  
302 cognitive workload [34]. It may indicate that drivers prioritized other driving sub-tasks more  
303 demanding than lateral control [34]. Thus, the increased SDLP observed here does not seem to  
304 be induced by MW. Then, the other possible explanation could be linked to the high levels of  
305 arousal which defines anger. As stated by Logan and Crump [35], when a conscious monitoring  
306 of a low-demanding task is possible, the performance obtained for this task can be disrupted.  
307 Thus, if arousal can rise the amount of available attentional resources [36], the participants in  
308 the anger session may have allocated attention to their internal thoughts for one part and to a  
309 conscious monitoring of the vehicle lateral control for another part. This last can explain the  
310 increased variation of lateral position provoked by anger. However, Ünal et al. [37] asked to  
311 their participants to listen to music of their choice while performing the same car following

312 task. They observed that a high level of arousal could reduce the standard deviation of lateral  
313 position [37]. This effect was found with a musical playlist set up by the participants.  
314 Unfortunately Ünal et al. [37] did not assess the valence dimension in their study. This issue  
315 raises the question about the role of valence. Thus, future research should take into account this  
316 dimension so as to disentangle the effects of moods defined by a similar level of arousal on  
317 lateral variations.

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

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

333

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337

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