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Driver's emotional state and detection of vulnerable road users: towards a better understanding of how emotions affect drivers' perception using cardiac and ocular metrics

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30 **Driver's emotional state and detection of vulnerable road users: towards a**
31 **better understanding of how emotions affect drivers' perception using**
32 **cardiac and ocular metrics**

33

34 Traditionally, anger has been considered to have a detrimental effect on driving.
35 However, recent studies suggest that this statement should be qualified, especially where
36 vulnerable road user detection is concerned. One primary factor which may determine
37 anger's effect on a driver's attention is its intensity. In the present study, different
38 intensities of anger were elicited via film clips, then performances in vulnerable road user
39 detection (i.e., of cyclists) were assessed while participants drove a car in a simulated
40 environment. Cardiac and ocular measurements and self-reported data were used in order
41 to accurately assess emotional state and attention management throughout the
42 experiment. Results suggested that participants resorted to reappraisal strategies when
43 they were exposed to the emotional film clips. This phenomenon did not directly affect
44 cyclist detection performances, but evidence of different visual scanning strategies
45 between groups emerged. The contribution of cardiac and ocular measurements to
46 emotional assessment and the advantages of appraisal approaches of emotion were also
47 discussed.

48 Keywords: anger; vulnerable road users; driving simulation; autonomic nervous system;
49 heart rate variability; eye-tracking

50

51 **1. Introduction**

52 **1.1. Context**

53 Nowadays, many wheeled vehicles share the same space, and recent statistics have
54 highlighted a human failure in managing the numerous interactions between road users. In
55 2015, the number of deaths on French roads increased for the second time in a row, by 1.7%
56 compared to 2014. More specifically, pedestrians and cyclists, who are considered to be
57 vulnerable road users (VRU), represented 18% of deaths in 2015, just behind motorists (52%)
58 and motorcyclists (22%) (The French Road Safety Observatory, 2016). The same report also

59 shows that the main causes of accidents involving pedestrians and cyclists are collisions with
60 other road users, mostly motorists (69% and 52% respectively). In addition to the traditional
61 factors involved in a crash (e.g., speed, inappropriate drinking), a lack of VRU visibility has
62 also been reported (The French Road Safety Observatory, 2016). Consequently, the aim of the
63 present research was to investigate the cognitive processes which affect the way drivers detect
64 cyclists, whose presence on the streets of French cities is on the increase (Bouaoun, Haddak, &
65 Amoros, 2015). As attention management is required to detect some stimuli while carrying out
66 a second task (Wickens, 2002), the exploration of the online processes which draw an
67 individual's attention to a VRU during driving, especially when drivers are asked to detect
68 VRUs, appears worthy of interest. In this context, conspicuity, which is the inherent ability of
69 the stimuli to attract an individual's attention (Engel, 1971) emerges as an intriguing concept.

70

71 **1.2. Conspicuity and attention in driving**

72 "Two main types of attention are commonly distinguished in the literature: bottom-up
73 or *stimulus*-driven and top-down or *goal-oriented* attention" (Nikolla, Edgar, Catherwood, &
74 Matthews, 2018). Bottom-up attention is determined by the physical characteristics of the
75 information attended to, whereas top-down attention is guided by the observer's goals.

76 The earliest studies investigating conspicuity focused on the physical characteristics
77 (e.g., shape, brightness, color, size) that make stimuli salient from their surroundings (Hancock,
78 Wulf, Thom, & Fassnacht, 1990; Wulf, Hancock, & Rahimi, 1989). When this is the case,
79 attention is mainly guided by bottom-up processes and is linked to the concept of sensory
80 conspicuity.

81 More recent studies, notably related to research in the driving field, have shown that
82 the focus of attention can also be influenced by expectations, objectives and knowledge relating

83 to a stimulus (Hole, Tyrrell, & Langham, 1996; Magazzu, Comelli, & Marinoni, 2006; Rogé et
84 al., 2017; Rogé, Douissembekov, & Vienne, 2012). When this is the case, top-down processes
85 associated with the concept of cognitive conspicuity, are involved in perception. According to
86 Rogé, El Zufari, Vienne and Ndiaye, (2015), other components such as the driver's emotional
87 state might also play a role in driving activity, especially VRU detection abilities. Therefore,
88 the study of emotions could lead to a better understanding of situations in which motorists have
89 to detect VRUs

90

91 **1.3. Emotion and attention in driving**

92 Previous studies have shown that emotion can affect a driver's attention management
93 while driving. According to Ellis and Moore (2005), negative emotions are likely to elicit
94 thoughts which are unrelated to driving activity. This phenomenon tends to decrease overall
95 attentional resources. This in turn leads to inattention toward key activities (which are essential
96 to ensure safe driving), for instance the detection of other road users (Regan, Hallett, & Gordon,
97 2011). Several studies which are consistent with this idea, have demonstrated that negative
98 emotions can impair driving. Pêcher, Lemercier and Cellier (2011), for example, showed that
99 sadness was associated with degradation of performance due to irrelevant thoughts such as
100 rumination and self-focus while driving. According to Jeon, Walker and Yim (2014), fear
101 (assessed through Likert-type scales) can reduce drivers' attentional focus. Nesbit, Conger and
102 Conger (2007) highlighted a link between anger and aggressive driving. Additionally, Garrity
103 and Demick (2001), showed that anger, assessed using the NEO Personality Inventory (NEO-
104 PI-R)¹ and the Profile of Mood States (POMS)², led to an overall negative driving behavior.
105 According to Jeon, Walker and Gable (2015), anger assessed via Likert-type scales could also

¹ (Costa & McCrae, 1992)

² (McNair et al., 1992)

106 trigger dangerous modulations in driving style. Stephens, Trawley, Madigan and Groeger
107 (2013) used an impeding vehicle and close rear traffic to elicit anger in participants who had to
108 drive in a simulator in order to specifically study road user detection abilities. Using the Profile
109 of Mood States Short Bilingual Version (POMS SBV)³ to assess emotions, they observed that
110 anger-provoked drivers spent a considerably smaller proportion of time initially looking at less
111 apparent pedestrians or emerging vehicle events than control drivers. They also took longer to
112 make corrective actions to avoid potential collisions. Anger-provoked drivers tend to resort to
113 a more superficial processing of potential hazards, and consequently underestimate the inherent
114 risk of certain driving situations.

115 Contrary to these studies which underscore the detrimental effects of negative emotions
116 - especially anger - during driving, other studies highlight the positive effects of anger on
117 driving activity. Techer, Jallais, Fort and Corson (2015) used the Attention Network Test–
118 Interactions (ANT-I) paradigm⁴ which is a single task allowing the assessment of different
119 attentional networks at the same time. They used ANT-I after eliciting anger through
120 autobiographical recall procedure and checking the efficiency of their emotional induction via
121 Affect Grid⁵ and Brief Mood Introspection Scale (BMIS)⁶. They found a positive impact of
122 anger on the alerting network which is dedicated to the preparation and sustainment of alertness
123 when a high priority signal needs to be processed. According to Posner and Petersen (1990) this
124 network is one of three independent networks of attention (i.e., alerting, orienting, and executive
125 control). The authors concluded that anger could broaden the scope of the attentional focus via
126 the alerting network.

³ (Cheung & Lam, 2005)

⁴ (see Callejas, Lupianez, Funes, & Tudela, 2005)

⁵ (Russell, Weiss, & Mendelsohn, 1989)

⁶ (Mayer & Gaschke, 1988)

127 Rogé et al. (2015) presented safety messages in order to improve the perception of VRU
128 vulnerability during driving. They assessed emotional state using an adapted version of the
129 Geneva Emotional Wheel (GEM)⁷ throughout the experiment. They observed that processing
130 safety messages increased the number of negative emotions felt by drivers. Among these, the
131 intensity of anger felt by drivers correlated positively with an improvement in their VRU
132 detection abilities. However, the authors were unable to conclude if the improvement in VRU
133 detection performances was due to the emotion felt or to the information provided during the
134 viewing of safety messages. In the present study, emotional elicitation was used to induce
135 different intensities of anger in order to understand how a negative emotion might affect cyclist
136 detection performances during driving. In this context, film clips, making no reference to road
137 safety, and giving no information about VRU vulnerability, were used.

138 If anger alone, experienced when viewing the film clip, improves motorists' attentional
139 abilities while driving, it could therefore be assumed that the effect of anger during driving
140 depends on the intensity of anger felt. In this context, the detrimental effect observed in many
141 studies (Garrity & Demick, 2001; Jeon et al., 2015; Nesbit et al., 2007; Stephens et al., 2013)
142 is likely to be linked to a high intensity of anger, as opposed to a moderate level of anger which
143 could be beneficial for cyclist detection as suggested by Rogé's results . Consequently, we
144 expected cyclist detection to be improved when a moderate intensity of anger was elicited, and
145 a deterioration in cyclist detection ability when the intensity of anger was high. This assumption
146 was called the *anger intensity threshold hypothesis*. In addition, as previously suggested by
147 Stephens's eye-movement results, it could also be assumed that different visual scanning
148 strategies would emerge across groups when individuals experienced different intensities of
149 anger.

⁷ (Scherer, 2005)

150 As illustrated by some studies cited earlier, questionnaires and scales are commonly
151 used to assess emotional state. However, some works have shown that using a combination of
152 self-reports, physiological data and behavioral measures is a very efficient way to infer mental
153 processes (Smallwood & Schooler, 2015) or emotional states (Valverde, Lera, & Fernández,
154 2010). Hence, the question of how to best record reliable evidence of individuals' emotional
155 state remains.

156

157 **1.4. Physiological assessment of emotional state**

158 According to Kreibig (2010), the study of the autonomic nervous system (ANS) is
159 particularly relevant when investigating emotion. The ANS can be divided into two main
160 branches: the parasympathetic nervous system which has an inhibitory effect on cardiac
161 muscles through vagal efferent nerves, and the sympathetic nervous system which excites
162 cardiac muscles via the norepinephrine neurotransmitter (Ruscio, Bos, & Ciceri, 2017).
163 Consequently, cardiac measures such as heart rate (HR), defined as the number of contractions
164 of the heart per minute (bpm), and heart rate variability (HRV), which is the fluctuation in the
165 time interval between heartbeats, are commonly used to determine which of the ANS
166 components (i.e., sympathetic or parasympathetic) dominates. These measures therefore allow
167 inferences to be made on the type of emotional processing used when individuals appraise
168 stimuli or events (Kreibig, 2010; Niedenthal, Krauth-Gruber, & Ric, 2006). According to
169 Kreibig (2010), HR increase and overall HRV decrease, both reflecting sympathetic dominance,
170 are usually observed when anger is experienced. However, HRV analysis regroups several
171 domain methods (i.e., time, frequency and nonlinear) of RR interval series processing, and a
172 number of indices can be calculated for each one of these.

173 Some of these are used often, especially the standard deviation of the average NN
174 interval⁸ calculated over short periods (SDANN), and pNN50 which is the proportion of interval
175 differences of successive NN intervals greater than 50 ms, both related to the time domain
176 method. Power spectral density collected for high frequency band (HF) and low frequency band
177 (LF) of interval tachograms are also often used as frequency domain indexes. The nonlinear
178 domain is used less, probably because processing of some of the indexes is complicated.
179 Nevertheless, because interpretation of their results is relatively easy, some indexes are worth
180 processing (Tarvainen, 2014). In this context, we only focused on the Poincaré plot which is a
181 graphical representation of the correlation between successive RR intervals. Two indexes (SD1
182 and SD2) can then be calculated, along with sample entropy (SampEn) which is a reliable
183 estimator of the complexity of a signal especially for short time series (<200points) (Riganello,
184 Cortese, Arcuri, Quintieri, & Dolce, 2015).

185 All these indexes either provide information about short-term variability in cardiac
186 rhythm (e.g., pNN50, SD1, HF), or describe long-term variability (SDANN, SD2, LF) or signal
187 complexity (e.g., SampEn). While long-term variability in cardiac rhythm tends to represent
188 the sympathetic branch of the ANS, short-term variability refers to parasympathetic dominance
189 (Task Force of The European Society of Cardiology and The North American Society of Pacing
190 and Electrophysiology, 1996). In addition, according to Valenza, Allegrini, Lanatà and Scilingo
191 (2012), rest is characterized by chaotic behavior dynamics that cause entropy increase. By
192 contrast, entropy tends to decrease with arousal increase. As arousal variations broadly correlate
193 with ANS activity (Salvia, 2012), entropy variations could thus provide information about ANS
194 activity.

⁸ (i.e., the interval from one R peak to the subsequent R peak)

195 In the literature on cardiovascular indexes of HRV related to anger, Francis, Penglis and
196 McDonald (2016) found a significant increase in SDNN values after an anger inducing task. In
197 addition, Kop et al. (2011) found that the level of frustration in an anger recall task tended to
198 be associated with higher LF values. Marci, Glick, Loh and Dougherty (2007) also found a
199 significant decrease in HF values in participants who had to listen to anger scripts while trying
200 to imagine the event portrayed as vividly as possible. These studies all illustrate sympathetic
201 dominance when anger is experienced. However, cardiac measurements are not the only way
202 to assess ANS activity.

203 Some studies have revealed a relationship between pupillary size, the ANS and
204 emotions. While pupil dilation is mediated by the sympathetic system, pupil contraction is
205 under parasympathetic system control (Sirois & Brisson, 2014). Emotional arousal is associated
206 with pupil size variations. Emotions with a high arousal (e.g., anger) tend to increase pupil size
207 (Bradley, Miccoli, Escrig, & Lang, 2008). In addition, according to Okutucu et al. (2016), there
208 are a number of correlations between dynamic pupillometry (i.e., a set of different metrics
209 related to pupil dilation and contraction as well as velocity and duration of pupil contraction
210 and dilation) and some of the previously cited indexes of HRV (e.g., SDANN, pNN50, HF and
211 LF/HF). Consequently, links can also be made between autonomic functions assessed by pupil
212 and cardiac measures. To the best of our knowledge, no study couples cardiac (HR and HRV)
213 and pupillary data in order to assess different intensities of anger.

214 In the light of previous studies, it was assumed that the sympathetic branch of ANS
215 would dominate an individual's overall autonomic nervous activity when anger was
216 experienced. This phenomenon would be further amplified as the intensity of anger elicited
217 became stronger. This assumption was named the *sympathetic dominance hypothesis*.

218

219 2. Method

220 2.1. Participants

221 Forty-five participants (18 males, 27 females), aged between 19 and 42 years
222 ($M = 28.5$; $SD = 5.8$) took part in this experiment. They all had at least two years of driving
223 experience. On average, they used their car four times a week and covered more than 150
224 kilometers per week. All participants reported normal or corrected-to-normal vision and
225 audition.

226

227 2.2. Material

228 2.2.1. Film clips

229 Three film clips retrieved from a previous study (Schaefer, Nils, Sanchez, & Philippot,
230 2010) were selected on the basis of their propensity to elicit a neutral state and two levels of
231 anger. For the anger-inducing film clips, the selection was based firstly on a set of 10 film clips
232 with high anger discreteness scores (i.e., mean score obtained on the anger item of the
233 Differential Emotions Scale (DES)⁹, minus mean scores obtained on all remaining items of the
234 DES). Two of the film clips with the highest anger discreteness scores (i.e., film clips with the
235 highest propensity to elicit anger) were then selected on the basis of their mean anger scores on
236 the DES. In this way, we chose two film clips that potentially elicited anger at different levels:
237 slight (no. 30 in the Schaefer's baseline with an anger score of 3.16) and strong (no. 2 with an
238 anger score of 5.04). For the neutral film clip, we selected a clip (no. 49) with a very low level
239 on the anger item of DES (anger score of 1). Precautions were also taken regarding this clip,

⁹(Izard, Dougherty, Bloxom, & Kotsch, 1974)

240 for which no other item of DES exceeded a score of 1, thus ensuring that the film clip could be
241 considered as neutral.

242 The neutral film clip showed a woman walking along the street in a market-place
243 shopping area. The film clip inducing slight anger showed a man undergoing intense
244 interrogation, and the film clip inducing strong anger showed a man randomly shooting people
245 from his balcony. Because the film clips were of different lengths, we made changes to obtain
246 three comparable videos (mean length = 1 mn 55 s; SD = 10 s).

247

248 2.2.2. *Emotional wheel (EW)*

249 To measure the intensity of anger felt by participants, we used the Emotional Wheel
250 (EW) (Rogé et al., 2015). This tool is a visual analogue scale from which the intensity of anger
251 can be extracted and converted into a percentage.

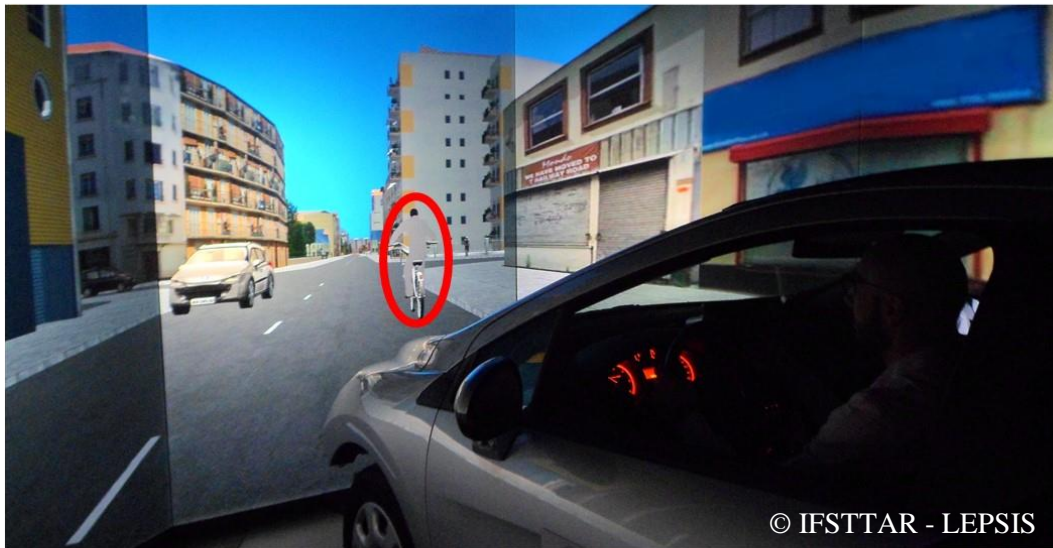
252

253 2.2.3. *Apparatus*

254 *Driving simulator.* A car-driving simulator (Figure 1) was used to reproduce the same
255 driving conditions for all participants, and ensured their absolute safety. It consists of a Peugeot
256 308 car cabin equipped with a video projector set behind each of the five screens (size:
257 2.25 m x 8.25 m at a horizontal visual angle of 180°) used for the road scene ahead, and one
258 screen (size: 2.25 m x 3.00 m) behind the cabin for the inside rear view, with a video projector
259 hung from the ceiling. Two monitors (size: .56 m x .48 m) installed on both sides of the cabin
260 at the same height as exterior flat mirrors (at a distance of 1.08 m from the mirrors) enabled
261 participants to monitor the road environment to the side of, and behind their car. Road images
262 were projected at an average refresh rate of 59 Hz, and driving data were recorded at the same

263 frequency. Traffic and car engine sounds were played through a wooden subwoofer and two
264 satellite speakers placed on each side of the participant.

265



266

267

268 *Figure 1.* The OSG-Sim² simulator in the LEPSIS unit at IFSTTAR including an example of
269 the type of cyclist (circled in red) participants had to detect

270

271 *Electrocardiogram.* A Bionomadix transmitter (BIOPAC Systems Inc.) allowing
272 wireless connection with an MP150 data recording system (BIOPAC Systems Inc.) was used
273 to collect cardiac signals. Electrocardiogram (ECG) was continuously recorded and sampled at
274 1000 Hz from the cardiac baselines until the end of the experiment. The ECG was analog low-
275 pass (.05 Hz) and high-pass (35 Hz) filtered at acquisition, as an approximately 5–30 Hz range
276 covers most of the frequency content of QRS complex (Pahlm & Sörnmo, 1984). Triggers,
277 which were manually positioned during the recording to define the beginning and end of the
278 baseline, and of the film clip session, were automatically sent by the simulator to the ECG at
279 the beginning and end of the driving session to ensure accurate synchronization.

280 *Eye tracking.* The Mobile Tobii Glasses Eye-Tracker was used to continuously record
281 participants' eye position from when film clip viewing began until the end of the experiment.
282 The glasses provided video-based eye tracking using the dark pupil and corneal reflections and
283 the embedded scene camera operated at 30 Hz with 56° x 40° scene coverage.

284

285 **2.3. Procedure**

286 The experiment began with several tests (e.g., Monoyer, Parinaud, Ishihara, and Useful
287 Visual Field) in order to measure individuals' visual acuity (from near and far), their ability to
288 discriminate colors, and the size of their visual field respectively.

289 Three Ag-AgCl pre-gelled electrodes were then attached to the participants following a
290 modified lead II configuration. Electrodes were connected to the Bionomadix transmitter
291 (BIOPAC Systems Inc.) to record participants' cardiac activity. After a few seconds of
292 recording to ensure the equipment was functioning correctly, participants were seated
293 comfortably in the driving simulator. They then carried out a driving training session in an
294 urban environment. They were also asked to respect the Highway Code and to detect VRUs
295 without making any mistakes. In order to do this, they had to activate the headlight lever behind
296 the steering wheel as soon as they detected pedestrians or cyclists. These training sessions
297 allowed participants to become familiar with the simulator and to accustom themselves to the
298 lever used to indicate detection of VRUs.

299 Participants were then equipped with the eye-tracker outside the car driving simulator.
300 A system-guided 9-point calibration was performed until the highest possible tracking quality
301 was achieved. Participants returned to the driving simulator, were comfortably seated and were
302 asked to relax for 5 min in order to record cardiac baseline. This 5 min rest session was divided
303 in two: 2 min 30 s with their eyes closed and 2 min 30 s with their eyes open. The closed-eye

304 period allowed individuals to calm down, and the open-eye period was considered as the cardiac
305 baseline standard.

306 They then watched one of the three film clips on a large screen (visual angle of
307 31° x 17°) while still sitting in the simulator. The sound track was played through speakers
308 positioned behind the participant in order to create an immersive watching situation.
309 Participants were randomly assigned to one of the three experimental conditions. Before and
310 after viewing the film clip as well as after the driving session, participants were asked to assess
311 the highest emotional intensities of anger they felt throughout each stage respectively.

312 Finally, participants carried out a second driving task which lasted approximately five
313 minutes. They were instructed, as during training, to respect the Highway Code and to detect
314 VRUs (10 pedestrians and 5 cyclists) in an urban environment as quickly as possible without
315 making any mistakes. It should be noted that only cyclist detections were analyzed. Pedestrians
316 were used as decoys to orient the attention of participants towards the whole road scene, and to
317 distract them from the real targets (i.e., cyclists), as might be the case when driving in a real
318 environment. When driving was completed, participants had to complete the EW. The total
319 experiment lasted about an hour and a half.

320

321 ***2.4. Measures***

322 Subjective intensity of anger was assessed using the Emotional Wheel (EW). Data
323 collected from this EW were recorded as lengths (in mm) between the beginning of each
324 segment of the wheel and the marks drawn on it by participants.

325 For cardiac data, each participant's filtered cardiac signal was visually checked to
326 correct any artifacts (see Berntson et al., 1997; Berntson & Stowell, 1998) for artifact correction

327 methods used). R peaks were detected on cardiac signal in order to calculate RR intervals
328 corresponding to the time between two R peaks. Several indexes were then calculated with RR
329 interval series using Kubios HRV software v.2.2. Heart Rate was computed in beats per minute
330 (b.p.m.).

331 We also computed a number of indexes obtained from HRV analysis. SDANN and
332 pNN50, were calculated first. An LF/HF ratio was also considered. This index gives
333 information about how power (i.e., RR interval variance) distributes as a function of frequency.
334 LF/HF ratio allows the partial inference of which ANS branch dominates. While LF ranging
335 from .04 Hz to .15 Hz represent long term variability which is a marker related to sympathetic
336 activity, HF ranging from .15 Hz to .4 Hz represent short term variability and are related to
337 parasympathetic activity.

338 In addition, a Poincaré plot, providing a graphic display of the correlations between
339 successive RR intervals (i.e., plot of RR_{j+1} as a function of RR_j) was also computed. Standard
340 deviation of the points perpendicular to the line of identity denoted by SD1 and SD2 were
341 analyzed in order to parameterize the shape's ellipse formed by cloud points describing short
342 and long term variability in cardiac rhythm respectively.

343 Sample entropy (SampEn) was computed through complex calculations of differences
344 between RR interval series in order to quantify the extent of signal entropy, in other words, how
345 anarchic the signal is (See Riganello et al., 2015; Tarvainen, 2014) for more information about
346 how SampEn is calculated).

347 Pupil size was estimated through an index. A value was calculated for each timestamp
348 corresponding either to a pupil dilation (i.e., >100) or to a pupil contraction (i.e., <100) with
349 one hundred corresponding to the average value of the pupil during the calibration. By doing
350 this, we were able to avoid inherent individual differences.

351 The delay between the first hit on cyclists and use of headlight lever (time for cyclist
352 detection) was computed as cyclist detection performance. The length of the first glance at the
353 cyclist (first glance length) was also calculated. Both metrics were expressed in milliseconds.
354 Finally, saccadic amplitudes (in degrees) were also computed to evaluate the ocular strategies
355 implemented by individuals during driving.

356 On the basis of the *sympathetic dominance hypothesis*, HR and pupillary size increase
357 combined with an increase in long-term variability indexes of HRV and a decrease in short-
358 term indexes was expected for both groups exposed to anger eliciting film clips compared to
359 those exposed to neutral film clips. This phenomenon was expected to appear at least during
360 the film clip watching stage when the effect of emotional induction was supposed to be still
361 present. This pattern would also be more salient in the strong anger group than in the slight
362 anger group, in which it would be more pronounced than in the neutral group.

363 In line with the *anger intensity threshold hypothesis*, the times for cyclist detection and
364 of first glance length in slight anger group participants was expected to be shorter than those
365 observed in the strong anger and neutral groups. Saccadic amplitude was explored in order to
366 find out whether specific visual scanning strategies emerged between the different groups.

367

368 **2.5. Data processing**

369 The assumptions underlying the ANOVAs were checked using the Kolmogorov–
370 Smirnov test for normal distribution and Levene’s test for variance homogeneity for all the
371 following analyses. Comparisons of means using a post-hoc Fisher LSD test were conducted
372 when significant differences appeared following ANOVAs. Means were considered as
373 significantly different when the probability of a Type 1 error was less than or equal to .05.
374 Mann-Whitney tests were conducted to compare groups when non-parametric tests were used.

375 For subjective data, a Kruskal-Wallis test was used due to non-normal distribution of
376 anger intensity prior to watching the film clip. An ANOVA was then performed on intensities
377 of anger felt after the film clip had been watched, with film clip (neutral vs. slight anger vs.
378 strong anger) as a between-subjects factor. Friedman's ANOVA was also conducted on
379 intensities of anger felt throughout the study, with stages (baseline vs. induction vs. driving) as
380 a within-subject factor. Wilcoxon tests were performed when significant differences appeared
381 following Friedman's ANOVA.

382 ANOVAs were conducted on cardiac data for HR, SDANN, pNN50, LF/HF ratio, SD1,
383 SD2 and SampEn at baseline (i.e. open eyes), for HR ratio (described below), pNN50, LF/HF
384 ratio, SD1 and SampEn during film clip viewing and for HR ratio, SDANN, pNN50, SD1, SD2,
385 SampEn during the driving stage, with film clip as a between-subjects factor (neutral vs. slight
386 anger vs. strong anger). By contrast, Kruskal-Wallis tests were performed for SDANN and SD2
387 during the film clip stage and for LF/HF ratio during the driving stage.

388 For ocular data, an ANOVA was conducted on pupil size for both film clip and driving
389 sessions, with film clip as between-subjects factor (neutral vs. slight anger vs. strong anger). In
390 addition, ANOVAs were performed for cyclist detection times, for first glance length and
391 saccadic amplitudes, and film clip was once again used as a between-subjects factor (neutral
392 vs. slight anger vs. strong anger).

393

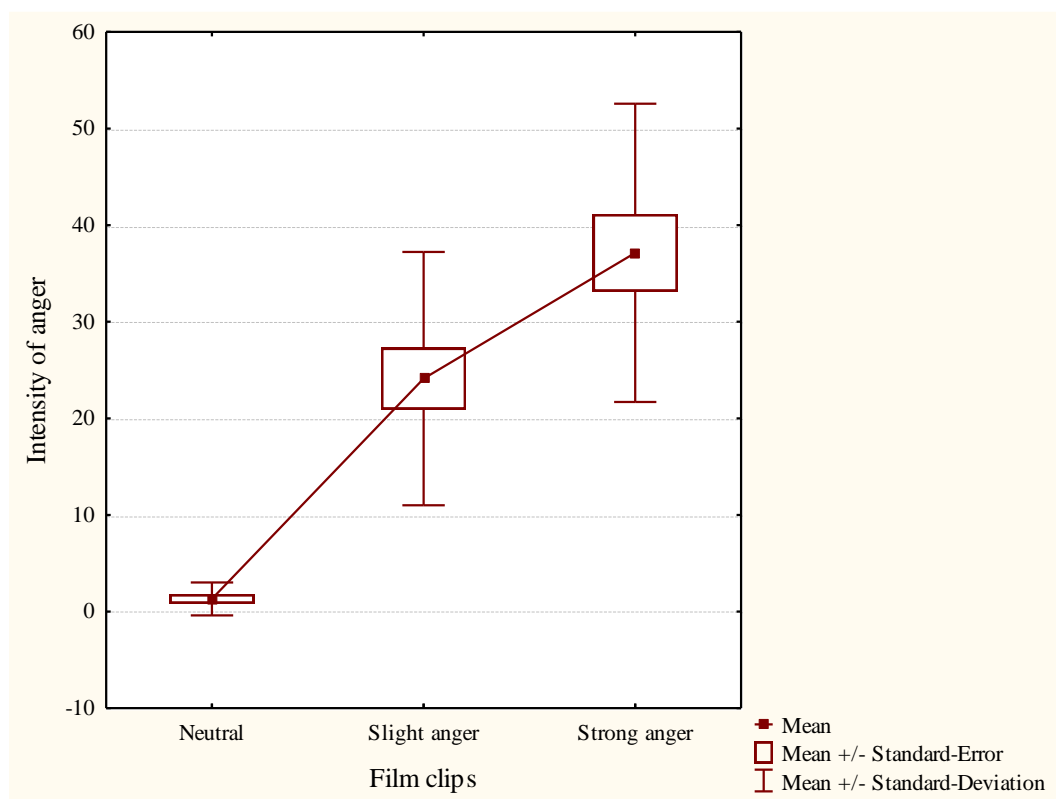
394 **3. Results**

395 *3.1. Emotional assessment using subjective data*

396 Results did not show any significant differences between groups regarding the
397 assessment of anger experienced before watching the film clips ($H(2, 44) = .64, p = .73$). The
398 intensity of anger felt by the three groups was therefore comparable before watching the film.

399 Significant differences appeared between groups in the anger assessments following film clip
 400 viewing ($F(2, 42) = 31.12, p = .001, \eta p^2 = .597$). LSD post hoc tests revealed that all intensities
 401 of anger significantly differed between the three groups ($p < .01$). The neutral film clip triggered
 402 the lowest level of anger ($M = 1.31, SD = 1.70$), the slight anger clip a moderate level of anger
 403 ($M = 24.12, SD = 13.11$), and the strong anger clip was rated with the highest intensity
 404 ($M = 37.13, SD = 15.44$) (Figure 2). Self-reported assessment therefore supported the
 405 efficiency of the emotional induction.

406



407

408

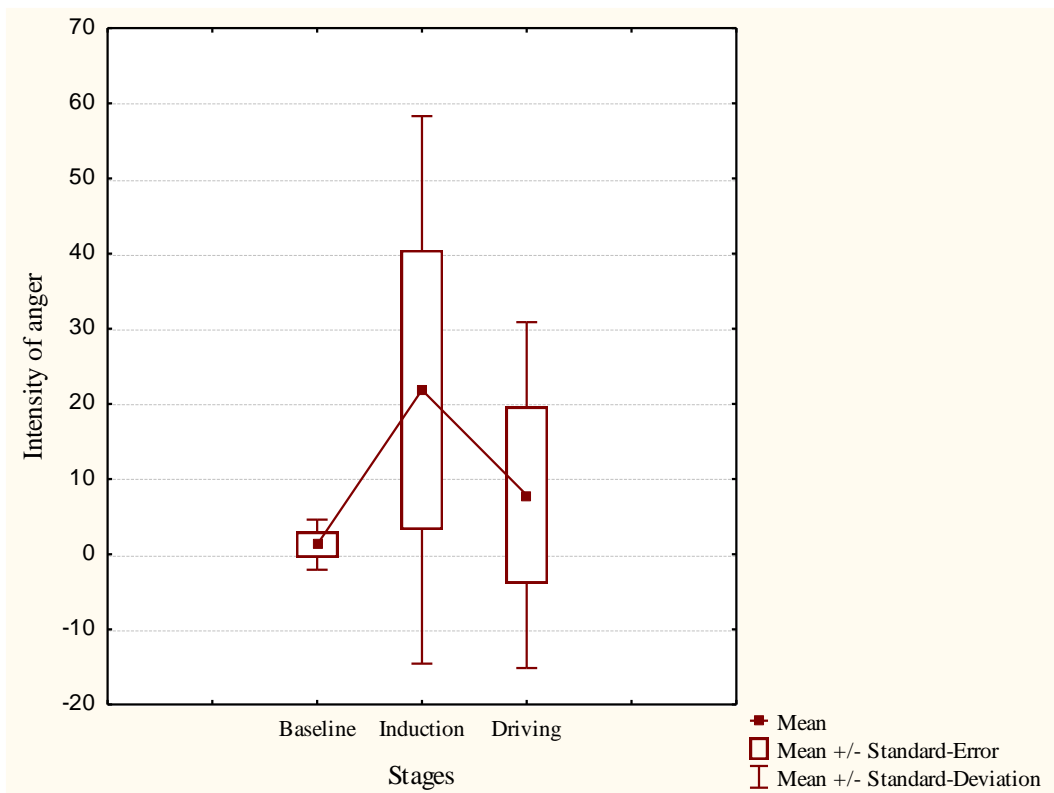
409 *Figure 2.* Intensity of anger felt during film clip viewing for the three groups

410

411 In addition, significant differences appeared between the anger assessments throughout
 412 the experiment ($Q(2, 45) = 47.09, p = .001$). Paired Wilcoxon tests revealed that all intensities

413 of anger significantly differed between the stages ($p < .001$) describing an increase of anger
414 intensity between the baseline ($M = 1.27, SD = 1.70$) and the induction stage
415 ($M = 21.87, SD = 18.59$) and a decrease between the induction and the driving session
416 ($M = 7.87, SD = 11.74$) (Figure 3). It should be noted that the intensity of anger for the driving
417 session was significantly higher than those obtained during the baseline session.

418



419

420

421 *Figure 3.* Intensity of anger felt throughout the different stages of the experiment

422

423 3.2. Emotional assessment using cardiac data

424 3.2.1. Baseline

425 Results at baseline did not show significant differences between groups for any cardiac
426 metric values ($p \geq .10$) except for HR ($F(2, 42) = 5.05, p = .01, \eta p^2 = .19$). We therefore
427 decided to compensate the effect of individual differences in subsequent analyses related to HR.
428 To this end, a ratio was used dividing the HR values collected during the film clip watching
429 stage and during the driving session respectively by HR values recorded at baseline.

430

431 3.2.2. During film clip watching

432 Results showed a significant effect of film clip ($F(2, 42) = 3.37, p = .04, \eta p^2 = .14,$
433 $CI = [.05, .08]$) on HR ratio. Significant differences between the neutral group
434 ($M = 1.02, SD = .04$) and strong anger groups ($M = .96, SD = .04$) as well as a limited effect
435 ($p = .06$) between the neutral and slight anger groups ($M = .98, SD = .08$) were observed,
436 indicating that anger-eliciting film clips triggered lower HR ratio values than the neutral film
437 clip.

438 Analysis of pNN50 revealed significant differences between groups
439 ($F(2, 42) = 4.23, p = .02, \eta p^2 = .17, CI = [27.05, 41.60]$), with lower values for the neutral
440 group ($M = 18.94, SD = 16.14$) than for the slight anger group ($M = 40.63, SD = 26.63$) and the
441 strong anger group ($M = 40.52, SD = 22.36$).

442 Results for the LF/HF ratio highlighted a significant effect of film clip
443 ($F(2, 42) = 3.45, p = .04, \eta p^2 = .14, CI = [1.02, 1.83]$), showing significant differences between
444 the neutral group ($M = 2.21, SD = 1.91$) and the slight anger group ($M = 1.15, SD = .86$), and
445 between the neutral and strong anger groups ($M = 1.07, SD = .91$).

446 Film clips had a limited effect on SampEn ($p = .09$), in the neutral group
447 ($M = 1.41, SD = .31$) in the slight anger ($M = 1.89, SD = .37$), and strong anger groups
448 ($M = 1.57, SD = .30$). No significant difference between groups was found for the following
449 indexes: SDANN, SD1 and SD2.

450

451 3.2.3. During the driving session

452 A significant effect of film clip on pNN50 was observed
453 ($F(2, 42) = 3.63, p = .04, \eta p^2 = .15, CI = [21.25, 33.09]$), with lower values for the neutral
454 group ($M = 15.47, SD = 10.70$) than for the slight anger group ($M = 31.30, SD = 21.76$) and the
455 strong anger group ($M = 32.63, SD = 20.03$).

456 However, film clips had a limited effect on LF/HF ratio ($p = .08$), in the neutral group
457 ($M = 2.90, SD = 1.83$), slight anger ($M = 2.30, SD = 1.94$), and strong anger group
458 ($M = 1.55, SD = .82$).

459 The same limited effect was observed for SD1 ($p = .06$) in the neutral group
460 ($M = 25.09, SD = 8.94$), slight anger ($M = 39.18, SD = 19.57$), and strong anger group
461 ($M = 42.69, SD = 25.95$).

462 Regarding SampEn, a significant effect of film clip was found between groups
463 ($F(2, 42) = 3.49, p = .04, \eta p^2 = .14, CI = [1.56, 1.72]$), with significant differences between the
464 neutral group ($M = 1.48, SD = .31$) and the slight anger group ($M = 1.70, SD = .26$), and
465 between the strong anger group ($M = 1.71, SD = .20$) and the neutral group. Film clips had no
466 significant effect on the following cardiac indexes: HR ratio, SDANN, and SD2.

467 Overall, analysis of cardiac data highlighted evidence of comparable physiological
468 patterns during film clip viewing and during the driving task (see Table 1). Interestingly, both
469 anger conditions differed from the neutral condition in almost all cases. However, the observed

470 variations, broadly describing short term variability dominance for anger groups, were
 471 unexpected and contradictory to the *sympathetic dominance hypothesis*.

472

473 Table 1

474 *Summary table of cardiac metrics variations throughout the different stages of the experiment*

Cardiac indexes	Film clip watching	Driving
HR ratio	Neutral > Strong anger (Neutral > Slight anger)	X
SDANN	X	X
pNN50	Neutral < Slight anger & Strong anger	Neutral < Slight anger & Strong anger
LF/HF ratio	Neutral > Slight anger & Strong anger	(Neutral > Strong anger)
SD1	X	(Neutral < Slight anger & Strong anger)
SD2	X	X
SampEn	(Neutral < Slight anger)	Neutral < Slight anger & Strong anger

475 X No significant differences were observed between groups

476 () Result based on limited effects

477

478 3.3. Emotional assessment using eye pupil size data

479 Results during film clip viewing firstly revealed a significant effect of film clip on pupil
 480 size ($F(2, 42) = 4.61, p = .02, \eta p^2 = .18, CI = [96.29, 102.98]$), with significantly higher values
 481 for the neutral group ($M = 104.34, SD = 10.72$) than for the values recorded for the strong anger
 482 group ($M = 93.20, SD = 6.98$). In addition, significantly higher values were observed in the
 483 slight anger group ($M = 101.72, SD = 12.29$) than in the strong anger group. However, no
 484 significant effect of film clip was found during the driving stage in the three groups.

485 Overall, the results regarding pupil size highlighted the emergence of a specific pattern
486 during the film clip stage. This pattern consisted of smaller pupil sizes in the strong anger group
487 only. This pattern was therefore not consistent with the *sympathetic dominance hypothesis* and
488 did not seem to be maintained during the driving session.

489

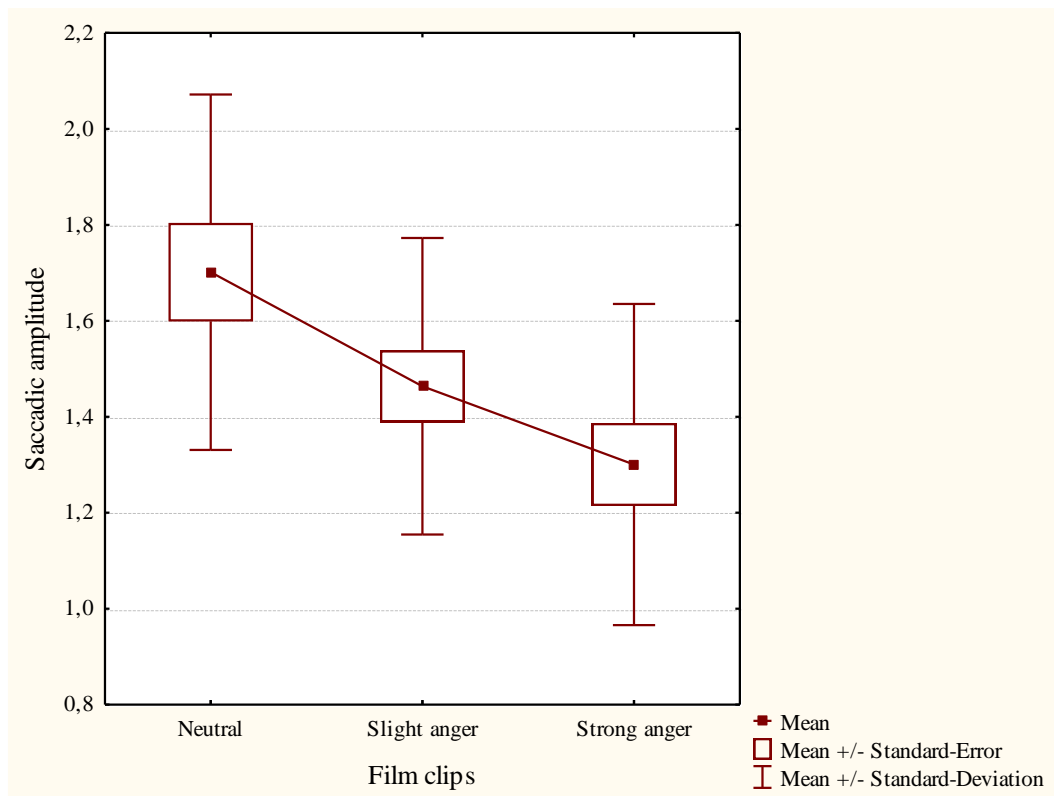
490 **3.4. Cyclist detection**

491 Results did not emphasize any significant effect of film clip either for cyclist detection
492 time ($F(2, 41) = .24, p = .79$) or for first glance length ($F(2, 42) = 1.11, p = .34$). This did not
493 support the *anger intensity threshold hypothesis*, and suggested that the emotional state induced
494 in this experiment did not affect VRU detection performances. Nevertheless, further
495 investigations needed to be carried out to determine whether emotional state affected
496 background processes such as visual scanning strategies while driving.

497

498 **3.5. Visual scanning strategies**

499 Even though results did not show a significant effect of the film clip variable on first
500 glance length and cyclist detection time, a significant effect of film clip was observed on
501 saccadic amplitudes ($F(2, 42) = 4.98, p = .01, \eta p^2 = .19, CI = [1.37, 1.59]$) with significantly
502 larger saccades for the neutral group ($M = 1.70, SD = .37$) than for the strong anger group
503 ($M = 1.30, SD = .33$). A trend ($p = .06$) towards larger saccades in the neutral group than in the
504 slight anger group ($M = 1.46, SD = .31$) also emerged (Figure 4). These results suggested that
505 groups did not use the same visual scanning strategies. This applied particularly to the anger
506 groups, particularly the strong anger group, whose ocular behavior when driving consisted of
507 smaller saccadic amplitudes.



508

509 *Figure 4. Saccadic amplitudes observed during the driving stage for the three groups*

510

511 **4. Discussion**

512 The aim of the present research was to investigate the role of anger in cyclist detection.
 513 Results for the film clip watching stage revealed that film clips elicited three distinct intensities
 514 of anger according to self-report. In addition, physiological data (cardiac and ocular) allowed
 515 us to differentiate the neutral group from the anger groups.

516 It should be remembered that, while SDANN and SD2 refer to long-term variability
 517 associated with sympathetic activity, pNN50 and SD1 are related to short term variability
 518 associated with parasympathetic activity. In addition, the LF/HF ratio provides a good
 519 illustration of the balance between short and long term variability (Tarvainen, 2014; Task Force
 520 of The European Society of Cardiology and The North American Society of Pacing and
 521 Electrophysiology, 1996). Furthermore, pupil size variations are closely linked to the ANS.

522 While pupil dilation seems to be linked to the sympathetic system, decrease in pupil size appears
523 to be mediated by the parasympathetic system (Sirois & Brisson, 2014).

524 In the present study, we found lower values of HR and LF/HF ratios, and higher values
525 of pNN50 combined with lower pupil size in participants who watched the anger film clips than
526 in those who watched the neutral film. Consequently, parasympathetic dominance can be
527 assumed during this stage for both anger groups. This is inconsistent with the *sympathetic*
528 *dominance hypothesis*. However, the question of what parasympathetic dominance means in
529 such a context (i.e., video watching) remains.

530 According to Luce, Payne and Bettman (1999) high levels of negative emotions induce
531 regulation strategies such as avoidance coping. Furthermore, other authors have highlighted
532 physiological patterns, especially cardiac patterns, describing this emotion regulation
533 phenomenon. Denson, Grisham and Moulds (2011), for example, asked three groups of
534 participants to watch an anger-inducing video. In one group (control), participants only had to
535 watch the video. In the second group (suppression), they had to try to control their facial
536 expressions and to behave in such a way that a person watching them would not know what
537 they were feeling. In the last group (reappraisal), participants had to manage their emotional
538 reactions; they were asked to try to maintain a neutral mood and not to be overwhelmed by the
539 anger elicited by the video. Researchers observed a significant increase in short-term variability
540 and decreased HR values among participants in the reappraisal condition. Similar types of
541 pattern were also observed in studies using pictures to induce a negative emotional state
542 (Kuoppa, Tarvainen, Karhunen, & Narvainen, 2016; Sarlo, Palomba, Buodo, Minghetti, &
543 Stegagno, 2005).

544 If Luce's rationale is followed, the existence of an anger threshold predicting the
545 establishment of reappraisal strategies seems feasible. In other words, in our study, individuals
546 exposed to the strong anger film clip could be expected to employ reappraisal strategies in order

547 to deal with bad feelings. However, since differences between groups were only observed for
548 both anger groups when compared to the neutral group, it can be assumed that this threshold
549 might be located below the intensity of anger elicited by the slight anger film clip. These results
550 suggest that both anger film clips elicited an excessively high intensity of anger, which, in turn,
551 drove individuals to implement reappraisal strategies to avoid being overwhelmed by negative
552 feelings.

553 Results obtained from self-report revealed high levels of anger for groups exposed to
554 the anger film clips. This result could be interpreted as an inefficient way of coping.
555 Nonetheless, the EW allows us to assess the extent to which individuals are affected by
556 emotions while watching the film clips without taking account of how people react when faced
557 with these emotions. One explanation could be that individuals were strongly affected by the
558 film clip at a particular moment, as shown by anger intensity scores collected from EW. They
559 then resorted to reappraisal strategies.

560 During the driving stage, a comparable physiological pattern also appeared for anger
561 groups when compared to the neutral group. pNN50 values tend to depict a dominance of
562 parasympathetic activity in individuals who watched one of the anger eliciting film clips. In
563 addition, SampEn values were significantly higher in both anger groups than in the neutral
564 group. According to Valenza et al. (2012), rest is characterized by chaotic behavior dynamics
565 manifested by increased entropy, which tends to decrease with arousal increase. As the
566 parasympathetic branch of the ANS is involved not only in rest states but also when reappraisal
567 strategies have been set up, the significantly higher value for SampEn when participants were
568 watching the anger film clips is congruent with an emotion-regulation strategy. Besides, self-
569 report revealed lower intensities of anger for all groups for the driving session when compared
570 to the induction stage. This result would either suggest that emotion-regulation strategies have

571 been effectively implemented for anger groups throughout the driving, or anger simply
572 decreased due to the attentional focus on the VRU detection task.

573 It should also be noted that we did not find exactly the same physiological results for
574 the film clip stage and during driving. One interpretation could be that unlike during the film-
575 clip viewing stage, individuals had to drive during the driving session. In this context, cognitive
576 processes such as attention management and motor activity are required. According to Porges
577 et al. (2007), motor activity is strongly related to ANS variations. Therefore, it is feasible that
578 driving affected the physiological variables studied. However, can it be assumed that the pattern
579 observed reflects only reappraisal strategies affected by driving activity?

580 According to Beauchaine (2001); Griffiths et al. (2017), sustained attention is
581 accompanied by parasympathetic dominance. Therefore, because of the instructions given to
582 participants during the driving task (i.e., to detect VRUs), it is possible that emotional elicitation
583 and implementing coping strategies affected the way that individuals subsequently managed
584 their attention to the targets, and became more attentive and more efficient in detecting VRUs.

585 When VRU detection performance was studied, there was no evidence to suggest that
586 emotion had affected this performance, since the film clips did not affect cyclist detection times.
587 However, on further investigation of ocular behaviors, results showed significant differences in
588 saccadic amplitudes between groups. Anger groups made smaller saccades than participants in
589 the neutral group. This result suggests that individuals in the anger groups adopted a specific
590 attention management strategy.

591 There are at least two explanations for this phenomenon. On one hand, it can be assumed
592 that anger-provoked people were in an optimal attention state as previously described. In this
593 case, their attentional management would be more efficient. In other words, they would
594 probably focus their attention more quickly on relevant space areas (i.e., cyclists they had to

595 detect). On the other hand, according to Mackenzie and Harris (2017), cognitive load could
596 impair visual scanning during driving. Consequently, it is also feasible that the conservation of
597 the coping strategies used during driving previously mentioned carried a cognitive cost, which,
598 in turn, manifested itself in smaller saccadic amplitudes. Future studies would be needed to
599 investigate this issue using, for example, assessment of cognitive load through (NASA, 1986)
600 or more quantitative measures such as functional near-infrared spectroscopy (fNIRS).

601 Overall, these results demonstrated that both cardiac measures and pupil size provide
602 interesting evidence of emotional state and allow diagnosis of the implementation of reappraisal
603 strategies. This research also raises some issues about the relevance of focusing on discrete
604 emotions. Appraisal approaches of emotion combined with physiological measurement seem
605 to be a better way of taking into account how individuals deal with emotional events. In
606 addition, there was no significant difference between groups regarding detection performances.
607 This point suggests that emotion, alone, in the absence of any reference to the vulnerability of
608 certain road users, was not sufficient here to improve VRU detection abilities. In addition, the
609 intensities of anger manipulated in this study did not replicate the beneficial effect on VRU
610 detection performances while driving found by Rogé et al. (2015). The next step will be to
611 combine vulnerability information with emotion in film clips used to elicit negative emotions,
612 to determine whether or not this can improve cyclist detection performance during driving. This
613 will help to provide guidelines on the most effective way of communicating in order to improve
614 VRU detection abilities in motorists.

615

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618

619 **6. References**

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