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ORIGINAL ARTICLE

Road safety communication effectiveness: the roles of emotion and information in motorists' ability to detect vulnerable road users

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Abstract
This study aimed to investigate the impact of the emotional and informational components of road safety communication on the motorists' ability to detect cyclists in an urban environment. Different communication supports (audiovisual, auditory, visual) were used to present road safety messages to elicit different intensities of a same pattern of negative emotions before performing driving on a car driving simulator. Subjective results (intensities collected with a visual analog scale) showed that all the communication supports elicited the same set of emotions where sadness was salient. However, no evidence was found concerning a congruent physiological pattern (cardiac and pupillary response) either during exposure to communication supports or during a subsequent driving task. Better cyclist detections were observed after exposure to the safety messages, regardless of the communication support used. This result was confirmed by a better attention management for all participants, as shown by the analysis of the number of saccades per minute, the fixation durations and the speed of head movements and a safer speed management in areas where cyclists were present. The type of communication support is less important than the message itself to deliver some negative emotions. The combination of low-intensity negative emotions with safety messages appears to be an efficient strategy for a successful road safety communication when the aim is to improve motorists' ability to detect cyclists. Perspectives in terms of on-board systems and guidelines for designing safety campaigns were also discusses, as well as limitations of this study.

Keywords Road safety communication · Emotion · Driving simulation · Attention management · Physiology

1 Introduction

The effectiveness of advertising has been widely studied for decades. Earlier research in this field focused on the socio-cognitive aspects of this type of communication, and researchers developed persuasion theories relating to advertising (Friestad and Wright 1994; Smith and Hunt 1978). Later, researchers have investigated the way in which advertisements are visually explored (King et al. 2019; Pieters et al. 1999), how the information they contain is memorized (Pieters et al. 1999), and to what extent being exposed to advertisements affects physiological and cerebral activity (Morin 2011; Mostafa 2020). Knowledge gained through research on advertisements could also provide a means of addressing other issues. According to Morin (2011), there is a "tremendous need" (p. 135) to improve our ability to convince people to adopt safe behaviors relating to health and road safety.

According to the European Commission, Vulnerable Road Users (VRUs) are defined as 'non-motorized road users, such as pedestrians and cyclists as well as motorcyclists and persons with disabilities or reduced mobility and orientation' (European Commission Directorate General for Mobility and Transport 2021). The number of VRUs killed in traffic has increased in many countries over the last

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few years (The International Traffic Safety Data and Analysis Group 2018). In France, according to The French Road Safety Observatory (2017), a large number of crashes involve this type of road user. The number of deaths increased dramatically by 19.4% for pedestrians and by 8.7% for cyclists between 2015 and 2016. In more than 60% of cases, these deaths were the result of collisions with motorists. Road safety communication is often used as an educational tool with a view to decrease road injuries (Dalton et al. 2020). Using different media (e.g., posters, TV, radio), it informs people about, for example, VRU vulnerability, and in doing so attempts to influence motorists' behavior. In addition, safety campaigns often elicit emotions to try to influence the audience's behavior (Albouy 2017; Lewis et al. 2007). More specifically, it is really common to use negative emotions such as fear (Simpson 2017; Tay and Ozanne 2002), disgust or sadness (Wakefield et al. 2010) to highlight the consequences of risky behaviors in road safety campaigns. Daignault and Paquette (2010) investigated the effectiveness of safety messages based on threat by combining subjective and physiological measurements. Their objective was to assess the emotions experienced by participants when exposed to the messages, and to explore how these affected cognitive processes related to information processing. Unfortunately, these authors, in line with the majority of other studies in this field, recorded no measurements during a subsequent driving task. Consequently, it is difficult to conclude about the real effectiveness of the messages on behavioral change. Even though, a potential link may be postulated between the emotions felt by the participants after being exposed to the messages and their propensity to change their behavior, subsequent behavioral evaluations might provide valuable complementary information. The assessment of, for example, motorists' ability to detect cyclists when driving, as a behavioral assessment of the message effectiveness, might prove interesting for testing the objective effect of this type of preventive communication.

Rogé et al. (2015) studied on thirty-four participants the effect of safety messages on VRU detection abilities using VRU visibility distance (i.e., the road distance between a participant and a VRU when the latter was detected by the participant). The authors showed that presenting safety messages relating to VRUs was able to impact top-down processes by affecting the perceived level of VRU vulnerability in motorists exposed to the messages. This factor therefore has an impact on motorists' ability to detect VRUs. However, the authors were unable to reach a conclusion on an effect of the emotions elicited by messages or the information provided on the vulnerability of certain road users.

In a previous study with forty-five, Lafont et al. showed that film clips unrelated to road safety with a propensity to elicit varying intensities of negative emotions did not increase the cyclist detection performance in motorists (Lafont et al. 2018). This suggested that different intensities of negative emotions alone (i.e., with no link to road safety) were not sufficient to improve cyclist detection abilities in motorists. Consequently, this research aimed to study the effect of a safety-related message eliciting a combination of different intensities of negative emotions on cyclist detection performances. To be more specific, we looked at whether the same item of safety information presented through different sensory modalities (alone or combined) could elicit a set of negative emotions with different intensities. In addition, we tried to determine whether or not these modality-declined messages affected motorists' ability to detect cyclists in a subsequent driving task.

2 Safety messages, multimodality and elicitation of emotion

According to Kreibig (2010), the film clip is one of the techniques most commonly-used to elicit emotions. In this article, our view of emotion takes its inspiration from the constructed approach of emotion (Barrett 2017; Lindquist et al. 2013) which suggests that emotions are not elicited in isolation with only one single discrete emotion at a time, but rather as a mix of several emotions. In that sense, results of a previous study involving thirty-six participants effectively showed that emotion blends can emerge following exposure to complex material such as emotional film clips (Lafont et al. 2019). Like film clips, road safety campaigns are sometimes audiovisual and often elicit emotions. Using road safety clips could, therefore, be seen as a relevant way of inducing emotions (especially, negative emotions due to their contents often related to crash and death). In addition, some researchers have demonstrated that high emotional advertisements generated a higher and more durable safe driving attitude score in comparison to the low emotional advertisement (Hamelin et al. 2017). Consequently, in this study, we tried to find a relevant way of eliciting different intensities of a same emotional blend using safety messages to compare their effect on motorists' ability to detect cyclist.

Even though in the study of Borawska et al., the intensity of some negative emotions has been manipulated by adding some new elements to the picture of a crash scene (e.g., blood), this technique remains questionable (see Borawska et al. 2020). Indeed, we cannot make sure that these new features did not elicit new emotions. In addition, as we wanted to use an audiovisual material, it is technically more difficult to add such new element to an audiovisual clip as compared to a picture. Another area of literature was, thus, explored: emotion and multimodality literature. Studies investigating the integration of information from different modality channels do so most frequently using audition and vision. Paulmann and Pell (2011) showed that emotional recognition is facilitated when several information channels are present simultaneously. This phenomenon may be partially explained by the "increased activation of emotion-related knowledge" (p. 200). In other words, emotional information from each modality would be integrated to form a unified impression suggesting a deeper cognitive processing when dealing with multimodal information. In addition, Spreckelmeyer et al. (2006) studied the neural basis of auditory-visual interactions during the processing of affect. In their study, they recorded the electrophysiological activity of participants during exposure to picture and voice pairs eliciting congruent or non-congruent emotions. The authors also asked participants to rate the picture and voice pairs' valence on 7-point scales (ranging from 1 = very sad to 7 = very happy). Their results underlined a close relationship between emotionally congruent modalities and cerebral activity describing a "modified processing of picture-voice pairs with matching affective valence" (p. 166). In other words, a congruent affective pairing between pictures and voices led to a specific electrophysiological pattern when compared to a non-congruent pairing. Consequently, it is likely that multimodal stimuli trigger a deep and integrated processing of affect through specific neural circuits, and induce a greater intensity of feeling than unimodal stimuli.

In this research, it was, therefore, assumed that emotions elicited by the same messages delivered through the combination of auditory and visual modalities would elicit emotions with higher intensities than those delivered through either visual or auditory modality channels on their own. This assumption was called the modality-related intensities hypothesis.

3 Emotional assessment

3.1 Emotional assessment through subjective data

Traditionally, feelings are assessed in two main ways. Discrete approaches to emotion assume a finite number of emotions (Ekman 1984; Izard 1977). Studies which opt for this approach often ask participants to choose a number of labels referring to one emotion or another (Kop et al. 2011; Lobbestael et al. 2008). Dimensional models suggest that emotion can be described according to broader features. Research which uses emotional assessment based on this kind of model usually asks participants to rate their feelings on dimensional scales including, for example, valence and arousal dimensions (Russell 1980) as, for instance, the self-assessment manikin from Bradley and Lang (1994).

However, as appraisal theories of emotion suggest (Frijda 1986; Schachter and Singer 1962), early cognitive processes evaluate the emotional event, understand what caused it and assess ways of coping with it. Consequently, it is likely that individuals' feelings depend not only on the characteristics of a given stimulus but also on the way that this specific stimulus is appraised. The concept of emotional intensity, defined as the degree to which individuals are affected by emotion (Scherer 2005; Scherer et al. 2013), is an important feature of emotion which must be taken into account. When the intensity felt is very strong, notably for negative emotions, it can lead to reappraisal strategies such as coping (Luce et al. 1999; Stephenson and DeLongis 2020). As suggested by Laghi et al. (2018), the propensity to be empathetic could act as a mediator. To be more specific, a positive correlation exists between empathy and cognitive reappraisal. Consequently, it is probable that the more empathetic someone is, the more he or she is likely to undertake empathetic actions (e.g., safer driving to avoid collision with cyclists). See also White and Buchanan (2016) for more considerations about the concept of empathy including its physiological, emotional, and cognitive components.

In this study, empathy was measured to verify the equivalence of this dimension across the groups exposed to the different safety supports. It is also important to be aware that, irrespective of the way in which a stimulus is appraised, the emotion felt might also affect some physiological variables.

3.2 Emotional assessment using physiological measures

The neurovisceral integration model (Thayer and Lane 2000, 2009) provides evidence that connections exist between areas of the brain involved in affect and emotional regulation, and cardiac activity, which comes under the control of the autonomous nervous system (ANS). Vagal efferent nerves in the parasympathetic branch of the ANS exert an inhibitory influence on cardiac muscle, and in the parasympathetic branch, the neurotransmitter norepinephrine has a stimulatory effect on cardiac muscle (Ruscio et al. 2017). Cardiac measurements, particularly heart rate (i.e., the number of cardiac contractions per minute), and heart rate variability (which expresses the variations between individual, consecutive heartbeats), are both widely used when attempting to decide which of the two ANS branches is dominant at a given time (Niedenthal et al. 2006).

For example, heart rate (HR) is expected to increase with anger and decrease with contentment, while heart rate variability (HRV) is expected to decrease with anxiety and increase for amusement (Kreibig 2010).

There are, however, other ways of assessing ANS activity. A number of studies have also highlighted a relationship between emotions, pupil size and the ANS. The sympathetic system, for instance, mediates pupil dilation, while the parasympathetic system controls pupil contraction (Sirois and Brisson 2014). In their 2008 study, Bradley et al. (2008) showed the existence of an association between emotional arousal and variation in pupil size. More specifically, their study provides support that pupil size increases with pleasant or unpleasant pictures as compared to neutral ones. This pupil dilation is associated with increased sympathetic activity (see also Wang et al. 2018 for a more recent study on that topic). In this study, HR, HRV and other cardiac measures described in the measure section, as well as pupil size will be used to identify what branch of the ANS dominates.

However, it has to be stressed that emotional assessment is something difficult. Kreibig (2010) conducted a review of the literature in which she tried to summarize the physiological patterns commonly observed for a set of frequently investigated emotions. Her study reveals that consensus is not always reached regarding the physiological pattern expected for a specific emotion because emotions are complex and contextual. This is notably the case for sadness, for which different patterns have been observed in the literature depending on the type of sadness (e.g., crying, non-crying, acute or anticipatory sadness) (see Table 2 p. 401 in the Kreibig review). In addition, eliciting a single specific emotion is experimentally difficult because a mix of emotions can emerge (Lafont et al. 2019). With that in mind, it appears important to assess the set of emotions elicited by a specific media such as road safety message to get a better view of the individual's overall emotional state and then get a better comprehension of the physiological pattern recorded.

As the presentation of road safety messages through auditory, visual and audiovisual communication supports is supposed to elicit the same mix of negative emotions with different intensities, it was assumed that the same physiological pattern would emerge for each communication support. This pattern would be further amplified as the emotional intensity elicited by the safety messages became stronger. This assumption was named the intensity—related physiological pattern hypothesis. The extent to which safety communication affects emotional state is an interesting indicator of its effectiveness (Morin 2011). However, the observation of any changes—e.g., cyclist detection ability by motorists—which might occur following exposure to safety communication is also an effective method.

4 Attention management and VRU detection abilities during driving

According to the literature, two types of attention can be distinguished (Nikolla et al. 2018). Attention can be top-down and goal-oriented, in which case it is governed by the goals and objectives of the observer at a given moment. Alternatively, attention can be bottom-up. When this is the case, it is driven by a stimulus and by the physical characteristics of the object or information observed. Consequently, when bottom-up attention is studied, the physical characteristics (e.g., shape, brightness, color and size) of a stimulus which make it stand out from its surrounding environment are the main focus (Hancock et al. 1990; Wulf et al. 1989).

More recent studies, particularly those relating to research on driving, show that an individual's expectations, objectives and knowledge of a given stimulus also influence the attentional focus, and when this is the case top-down processes influence perception (Hole et al. 1996; Magazzu et al. 2006; Rogé et al. 2012, 2017). Management of attention must, however, be assessed through the analysis of motorists' visual strategies during driving, irrespective of the type of attention under scrutiny.

Lemonnier et al. (2015) used eye-tracking measurements to study the dynamics of visual exploration in drivers approaching an intersection. In addition, Mackenzie and Harris (2017) found that horizontal visual scanning could predict efficient attention management. They effectively observed that participants who have better control of attentional resources, and consequently drive more safely, are better able to distribute eye movements to more relevant areas of the driving scene, especially when road complexity increases, as is the case in an urban environment. Lee et al. (2017) used head movements combined with physiological measurements to predict road accidents caused by negative emotional responses while driving.

In line with all the previous studies on attention management and VRU detection abilities, it was assumed that because road safety messages provide safety information affecting motorists' perception of VRU vulnerability, they would consequently lead to efficient attention management, safer driving behavior and better cyclist detection performances. The benefits of this message would be further amplified in accordance with the level of emotional intensity experienced during exposure. This assumption was named benefit of intensity—related messages hypothesis.

5 Methods

The following sections describe the different features of the protocol developed. The approval from our internal ethic committee was obtained to recruit participants and run this experiment.

5.1 Participants

Initially, 60 participants were recruited, for which a financial compensation was given at the end of the study. Among them, only 54 participants (26 males, 28 females), aged between 20 and 44 years ($M = 25.44$; $SD = 4.88$) completed this experiment because data for the six remaining were not exploitable due to various technical issues (e.g., ECG signal loss, eye-tracking signal loss or simulator failure).

The fifty-four participants were pseudo-randomly assigned to one of the three experimental conditions (see Procedure below for more information) to get a comparable number of participants and proportion of males females in each group. Additionally, all participants had a minimum of 2 years driving experience ($M=6.39$; SD = 4.85). Participants were non-cyclists (i.e., they stated not to regularly use bikes). This participants' feature was controlled in order not to skew the way they could react to the safety messages (i.e., being more or less affected by the emotion). In addition, it was important that participants are not familiar with the way the cyclists generally behave on the road to not anticipate too much how the cyclists might behave during this experiment. On average, they used their car four times, or more, in a week ($M=4.37$; SD = 1.93) and their average weekly driving distance was higher than 200 km. Additionally, they were never involved in any accident with cyclists. All participants reported normal or corrected to normal vision and audition. Finally, no participant undergoing any medical treatment was included in this study. Moreover, participants recruited were instructed via emails not to consume any drugs or stimulant drink the day of the experiment in order not to skew the physiological data recorded.

5.2 Materials

5.2.1 Communication supports

A short film which lasted 2 min was used as the audiovisual communication support. This first showed accident statistics on VRUs, especially cyclists, and information about the vulnerability of certain road users. Then, alternating sequences of a teenage girl riding her bike and a man driving his car were shown while a voice-over explained how peaceful the girl was. Then, an unexpected crash involving the cyclist and a car at an intersection in an urban environment was presented. The impact was so brutal that one could see the body of the teenager thrown away. The crash occurred because of the late detection of the cyclist by the motorist. Slow motion was also used to emphasize the crash period. Then, some sequences followed one another to illustrate the driver's guilt and the consequences for the teenager. The teenager was seen on a stretcher and the voice-over explained all the obstacles and broken dreams she would have to go through. The short film ended with the following safety message: "Be careful, some road users are vulnerable. This short film was converted into an auditory version (i.e., the sound track was retained but the video was removed) and a visual version (i.e., the video was retained without the sound track, and subtitles of the soundtrack content were added) in order to obtain three types of communication support using the same road safety message. This material was chosen to allow participants to make inferences between the cyclist injured in the short film and the cyclists involved in the driving tasks.

5.2.2 Questionnaires

5.2.2.1 Emotional wheel The intensity of negative emotions experienced during the experiment was measured using the emotional wheel (EW) (Rogé et al. 2015), as its visual analog scale allows the extraction and measurement of eight negative emotions (anger, frustration, contempt, disgust, guilt, shame, fear and sadness). In addition, it allowed comparing the results between the Rogé's and this study. It is a self-reported, categorical tool inspired from the Geneva emotional wheel (Scherer 2005) whose psychometric properties has been validated (Sacharin et al. 2012).

5.2.2.2 Empathy assessment A French validation of the interpersonal reactivity index (IRI) (Gilet et al. 2013) was used to assess participants' propensity to feel empathy for the characters in the communication supports. This questionnaire consists of 28 items which can be grouped into four components of empathy (i.e., fantasy, empathic concern, perspective-taking, personal distress). The psychometric properties of this questionnaire have already been tested and validated (Gilet et al. 2013). This measurement allowed controlling the propensity to be empathetic across participants.

5.2.2.3 Perceived cyclist vulnerability A questionnaire composed of a single visual analog scale was used to assess how vulnerable the cyclist was perceived while the participants were exposed to the safety message. The question asked was "Assess the cyclist vulnerability in the media that you have seen by positioning a mark on the horizontal line below". A 100 mm-long horizontal line ranged from "low" label to "high" label was located below the question and allowed getting scores from 0 to 100. This questionnaire was used right after the empathy questionnaire at the end of the experiment.

5.2.3 Apparatus

5.2.3.1 Driving simulator The same car driving simulator as previous studies (e.g., Rogé et al. 2015; Lafont et al. 2018) was used for that study. The simulator afforded standardized presentation of conditions across participants, and to guarantee their safety (see Fig. 1 for an illustration of the driving simulator used). It consisted of a Peugeot 308 car cabin, which was equipped with 6 video projectors and two monitors on each side of the cabin. This setting allowed participants to monitor the road environment to the front, the sides and to the rear of the vehicle. Traffic noise and car-engine sounds were relayed via a sound system. The car

Fig. 1 The car driving simulator used and an example, indicated by a red circle, of one of the cyclists to be detected by the participants (Color figure online)

driving simulator was located in a room with no window. All the ambient lights were turned off during the experiments, except the light emitted by the simulator screens. Regarding the temperature of the room, it was controlled with a heat controller and remained the same along the study.

5.2.3.2 Electrocardiogram (ECG) Cardiac signals were recorded via a Bionomadix transmitter (BIOPAC Systems Inc) with wireless connection to an MP150 data recording system (BIOPAC Systems Inc). Electrocardiogram recording, sampled at 1000 Hz, was continuous from baseline through to the experiment's end. An analog low-pass (0.05 Hz) and high-pass (35 Hz) filter was used during ECG data acquisition. This range was chosen because most of the frequency content of the QRS complex[1] falls between 5 and 30 Hz (Pahlm and Sörnmo 1984).

5.2.3.3 Eye tracking TobiProGlasses2 were worn by participants. These provided continuous recording of their eye movements at a sampling rate of 50 Hz. Recording began at baseline and continued till the conclusion of the experiment. The camera embedded at the scene, with an image size of 160° × 70°, provided video tracking of participants' binocular eye movements, in particular from the dark pupil and corneal reflections.

These glasses allow accurate measurement of pupil size. In addition, gyroscope and accelerometer sensors embedded in the glasses enabled the recording of head movements.

[1] See Salvia, 2012 (p.89) to get more details about the QRS complex.

5.3 Procedure

Figure 2 describes how the experiment has been set up. Each stage will be detailed below.

First, participants' near and far visual acuity (via Monoyer, Parinaud tests) was tested. Participants' ability to distinguish between colors and the size of their visual field were also assessed (via Ishihara and VISOR tests, respectively). Three Ag-AgC1 electrodes were attached to each participant in a modified lead II configuration. Cardiac activity was recorded by connecting these electrodes to a Bionomadix transmitter (BIOPAC Systems). Participants then entered the driving simulator, where they were given a short training session (4 min approximately) in an urban environment. They were then asked to detect pedestrians and cyclists as quickly as they could, while scrupulously respecting the Highway Code and without making any mistakes. Participants activated the headlight lever situated behind the steering as soon as they spotted either a pedestrian or a cyclist (see Fig. 1). At the end of this training session, participants were asked if they felt ready to start or if they needed more practice before starting the following stages of the experiment. At the same time, the experimenter controlled if some motion sickness symptoms appeared thanks to a short questionnaire that encompassed 15 items ranging from as "general discomfort" to "feel like belching" including "headaches", "ocular fatigue", "difficulties seeing", "increased salivation", "sweating", "nausea", "difficulties focusing", "heavy head feeling", "blurry sight", "dizziness (eyes opened)", "dizziness (eyes closed)", "vertigo", "unpleasant feeling in stomach". Participants were asked to circle among four labels ("none", "weak", "moderate", "severe") proposed for each item, the one that corresponded the best to their current state. Note that this questionnaire also included an item related to fatigue. This last item allowed controlling if participants had the same level of alertness before starting the driving scenarios. Participants had to evaluate how much tired they were with the same four labels than the motion sickness symptoms. The experiment was stopped if one of the items (i.e., motion sickness or fatigue) were higher than "moderate". Note that this never happened. The goal of this practice block was to familiarize the participants with driving in a simulator and the detection task. In addition, this session was used to make sure that participants felt enough confident with the task to perform and to prevent from a practice effect between the driving stages before and after exposure to the safety messages if this session was not performed.

Participants were then fitted with the eye-tracker, and a 1-point calibration was made. On their return to the simulator, participants were asked to relax for 4 min, during which cardiac baseline was recorded. This 4-min rest period was divided into two parts. Participants kept their eyes closed

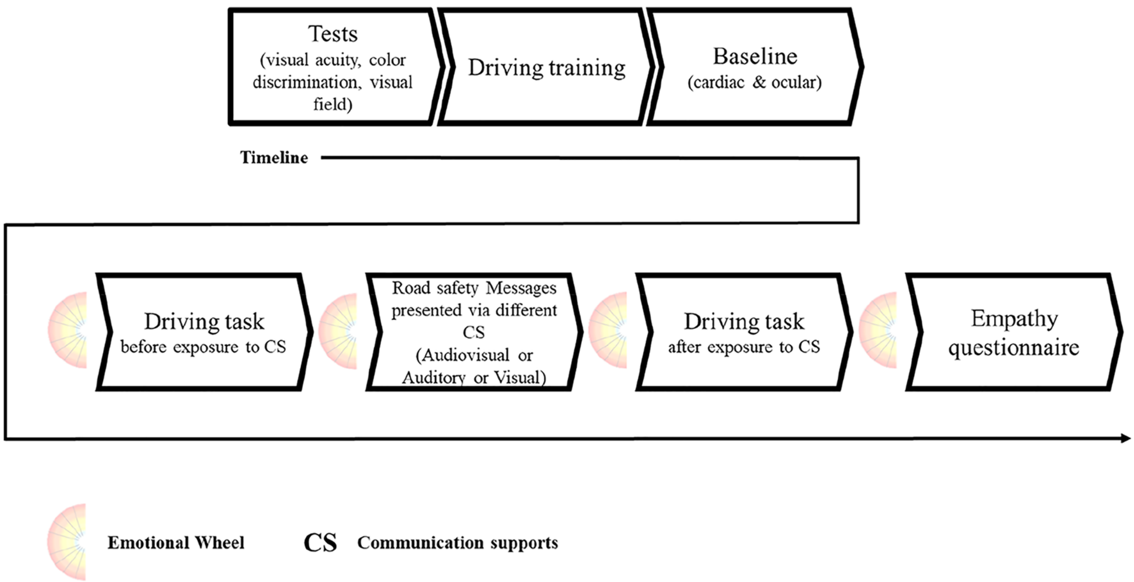

Fig. 2 Protocol summary

for 2 min (to allow them to become calm), and then opened them for 2 min (considered as their cardiac baseline).

In the next phase, participants performed a driving task (average duration 5 min 3 s; SD = 35 s). Their instructions were the same as in the training session, i.e., to detect pedestrians and cyclists as quickly as possible (ten pedestrians and five cyclists), in an urban environment, in accordance with the Highway Code and without committing any errors.

Participants were then pseudo-randomly exposed to one of the three communication supports (visual, auditory, audiovisual) while still sitting in the simulator without driving in order to get a comparable number of participants per group (i.e., 18 for the audiovisual group, 17 for the auditory group and 18 for the visual group) and a comparable proportion of men and women in each group. In details, nine women (24 years old, SD = 4) and nine men (27 years old, SD = 7) for the audiovisual group, nine women (21 years old, SD = 2) and eight men (27 years old, SD = 5) for the auditory group and ten women (27 years old, SD = 3) and eight men (27 years old, SD = 4) in the visual group. The video was presented to participants in the visual and audiovisual groups via a screen situated in front of them and at a visual angle of $31° \times 17°$. In the auditory and audiovisual groups, speakers placed behind participants relayed the soundtrack, creating an immersive environment. Participants were then asked to perform a second driving task on a comparable itinerary (average length 5 min 13 s; SD = 43 s). They received the same instructions as for the previous driving task.

It should be noted that, in both the driving sessions, only detections of cyclists were used in the data analysis. The pedestrians present in the scenes featured only as decoys and to incite participants to pay attention to the whole of the road scene as they would when driving in a real-life situation. A special focus was put on five cyclist detection situations for each driving scenario. In details, there was one situation where the cyclist came from the front, another from behind as well as two situations where the cyclist came from left or right sides in each driving task. The last cyclist detection situation consisted of a cyclist coming from the front in the first driving task whereas it was a right turn (i.e., cyclist coming from the rear while the car turns right) in the second scenario. Note that right turn has been previously identified as a critical VRU detection situation see Räsänen and Summala (1998) for an example. This situation was located at the end of the second scenario because a collision would have modified the participants' emotional state which could then affect driving.

After exposure to the communication support and after the baseline and driving tasks, participants were asked to assess the highest emotional intensities they felt for the eight negative emotions of the EW. At the end of the second driving task, participants were instructed to complete the empathy questionnaire. The total experiment lasted about 2 h.

5.4 Measures

Emotional wheel data consisted of the lengths (ranging from 0 to 55 mm) between the beginning of each segment of the wheel and marks drawn by each participant. The longer the distance from the center to the mark, the higher the intensity of the emotion considered is. Empathy for each participant was computed by analyzing the scores on the 28 scales of the questionnaire, each one varying from 0 to 4. The higher the scores, the more empathetic the participants are.

Cardiac readings obtained at baseline and during exposure to communication supports were analyzed to examine cardiac patterns relating to the emotional states induced by the types of communication support used in the experiment. A visual check was carried out on each participant's filtered cardiac signal, and artifacts were corrected (see Berntson et al. 1997; Berntson and Stowell 1998 for methods of artifact correction used). RR intervals were calculated, which correspond to the time between two R peaks, by detecting R peaks of cardiac signals. A number of other indices was then proceeded using the RR series and Kubios HRV Software, v2.2., with HR computed in beats per minute (b.p.m.). Seven indices obtained from HRV analysis were also calculated: the standard deviations of average NN intervals (i.e., intervals between normal R peaks) over short periods (SDANN); the proportion of successive NN intervals whose length exceeded 50 ms (pNN50); and the root mean square of successive NN interval distances (RMSSD). Those three indexes refer to short-term variability in the cardiac rhythm reflecting the parasympathetic activity. The low frequency/high frequency ratio (LF/HF ratio) was also studied, which provides information on the nature of the distribution of power (i.e., RR interval variance as a function of frequency). The dominant ANS branch can also be partially inferred from the LF/HF ratio. Low frequencies (LFs) situated between 0.04 and 0.15 Hz indicate long-term variability which is recognized as a marker of sympathetic activity. Short-term variability is expressed by high frequencies (HFs) situated between 0.15 and 0.4 Hz, and reflects parasympathetic activity.

A Poincaré plot, which illustrates in graph form the correlations between successive RR intervals (i.e., plot of RRj + 1 as a function of RRj), was also computed. Analysis was performed on the standard deviations of points perpendicular to the line of identity denoted by two standard deviations (SD1 and SD2) on the Poincaré plot. This allowed setting the shape formed by the ellipse of cloud points, which represent both short- and long-term variations in cardiac rhythm, respectively. More information regarding the aforementioned cardiac measures can be found in the Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology (1996).

Complex calculations on the differences between RR interval series were carried out in order to obtain a quantitative evaluation of the level of sample entropy (SampEn), namely, the extent to which a signal is anarchic (see Riganello et al. 2015; Tarvainen 2014 for a more detailed account of how Sample Entropy is calculated).

Pupil size was averaged from both eyes (in mm) for each timestamp throughout the acquisition of eye-tracking data. This metric was only analyzed for the two driving sessions where light environment was comparable between groups, as opposed to the stage where participants were exposed to the communication supports (cf. auditory support compared to the audiovisual and the visual supports). It was used as an index to assess emotional state (see Bradley et al. 2008) to see if the different intensities of emotions elicited by safety messages presented through different communication supports were maintained during the following driving task as detailed in the introduction section.

The number of saccades per minute, the saccadic amplitude (in pixels), the fixation duration throughout the driving tasks (in ms) and the speed of vertical and horizontal head movements (in° s^{-1}) (which provide gesture information) were also recorded and analyzed for both driving stages as opposed to the exposure to the communication supports (presence of subtitles only for visual group). These metrics were computed to obtain information on the dynamism of visual scanning strategies.

Accurate synchronization of driving and eye-tracking data was post-processed thanks to a visual trigger at the beginning of each driving scenario. It allowed calculating the time-lapse between the first fixation on a cyclist and the moment the headlight lever was activated. The two parameters were recorded in milliseconds (ms) and constitute cyclist detection performance that was called time for cyclist detection. ECG data recording was triggered separately by the experimenter when this visual trigger appeared. The possible lag induced by this method had a small impact on the ECG data analyses because the focus was put on large time windows while driving (i.e., several minutes).

While the time for cyclist detection provide information about the time needed by the motorist to indicate that he/she has detected the cyclist, the first fixation duration is an important metric which provide information about how a visual scene is explored (Lafont et al. 2018). In addition, as in Rogé's 2015 study, speed in key areas (in km h^{-1}) was also analyzed in order to provide information on the extent to which participants managed their speed in the presence of a cyclist. Key areas were defined as the areas covered by the participant while driving, between the moment when the cyclists started to move (i.e., when the participant crossed specific points on the road located near the cyclist detection situations) until they were detected by the participant. It should be noted that cyclists started to move a few seconds before becoming visible.

On the basis of the modality-related intensities hypothesis, emotional intensities collected after exposure to the audiovisual communication support were expected to be higher than for the visual or the auditory communication supports. In line with the intensity-related physiological pattern hypothesis, the physiological pattern resulting from the effect of the emotions elicited by the safety messages was expected to be more "salient" (i.e., values observed for the different cardiac and pupillary indexes would vary as those observed for the other experimental conditions, but would be higher or lower) in the group exposed to the audiovisual communication support than in the auditory and visual groups. On the basis of the benefit of intensity-related messages hypothesis, cyclist detection performances and metrics used to describe the dynamism of the visual scanning strategies were expected to reflect safer driving and better cyclist detection abilities after exposure to the audiovisual communication support than in the auditory and visual groups.

5.5 Analyses

The physiological and ocular data of one participant were not usable. Therefore, analysis of EW data was performed on 54 participants while other data were analyzed on 53 participants.

The Kolmogorov–Smirnov test for normal distributions was used to verify assumptions underlying ANOVAs. Variance homogeneity of all data was verified via Levene's test. Means were compared with a post-hoc Fisher LSD test. When the probability of a type 1 error was lower than, or equal to 0.05, means were deemed to be significantly different. Comparisons of non-parametric data were carried out using Mann–Whitney tests.

First, the equivalence of the empathetic dimension was verified across the groups exposed to the different safety supports. To do so, an alpha of Cronbach was performed on the mean scores for each participant on each main component of the empathy test (i.e., fantasy, empathic concern, perspective-taking, personal distress) to ensure that participants' responses were not aberrant. Alphas were considered as acceptable when the standardized value of α strictly exceeded 0.6. An ANOVA was then conducted the same scores with type of support (audiovisual vs. auditory vs. visual) as a between-subjects factor.

With the aim of studying the variation of the intensities of emotions elicited by the communication supports (audiovisual, auditory, visual) used for presenting road safety messages, each intensity of negative emotion from the EW has been analyzed comparing two moments: before exposure to the safety messages (i.e., after the first driving task) and after exposure to the safety messages. To do so, either a Wilcoxon or a repeated-measure ANOVA was used according to the way the data were distributed.

For the purpose of studying the effects of the different communication supports used for presenting road safety messages on the emotional state, EW data were analyzed using Kruskal–Wallis tests for the baseline and the exposure to communication supports stages (Fig. 2) with type of support (audiovisual vs. auditory vs. visual) as a between-subjects factor.

To study the effect of the different communication supports (audiovisual, auditory, visual) used for presenting road safety messages on cardiac data, ANOVAs were conducted on cardiac data for HR, SDANN, pNN50, RMSSD, SD1, SD2 and SampEn at baseline and during exposure to the communication supports, with type of support (audiovisual vs. auditory vs. visual) as a between-subjects factor. Kruskal–Wallis tests were performed for LF/HF ratio at baseline and during exposure to communication supports with type of support (audiovisual vs. auditory vs. visual) as a between-subjects factor due to non-normal distributions.

To study the effect of the different communication supports (audiovisual, auditory, visual) used for presenting road safety messages on the participants' driving behavior, repeated-measure ANOVAs, with exposure period for communication supports (pre-exposure vs. post-exposure), subsequently labeled exposure period factor, as a within-subject factor and type of support (audiovisual vs. auditory vs. visual) as a between-subject factor, were performed for pupil size, visual scanning metrics, speeds in key areas, times for cyclist detection and first fixation durations (the two last metrics were averaged from all cyclist detection situations).

Finally, to explore the persistence of emotion after being exposed to safety messages we also looked at how emotional intensities collected on the EW varied during the last part of the experiment (i.e., from exposure to safety messages to the second driving task). To this end, Wilcoxon tests were performed on the intensities of anger, contempt, guilt, disgust, shame and sadness with persistence as a within-subject factor (safety message vs. second driving task) due to non-normal distributions. Kruskal–Wallis tests were also conducted on the same intensities with type of support (audiovisual vs. auditory vs. visual) as a between-subjects factor. Regarding the intensities of frustration and fear, repeated-measure ANOVAs were conducted, with persistence (safety message vs. second driving task) as a within-subject factor and type of support (audiovisual vs. auditory vs. visual) as a between-subject factor due to normal distribution.

6 Results

A preliminary analysis of the data related to vulnerable road user detections was carried out. Results showed that participants detected more than 80% of pedestrians (used as decoys) and more than 90% of cyclists during the experiment. These high percentages suggest that participants had followed the instructions requesting them to detect vulnerable road users. It is also worth noticed that 30% of participants failed in detecting the cyclist in the right turn situation of the second driving task regardless of the message delivered. This percentage is particularly high as compared to those observed for the other cyclist detection situations, for which the percentage of detection failure varied between 2 and 8%. As motor response (i.e., activating the headlight lever) was needed to calculate the times for cyclist detection,

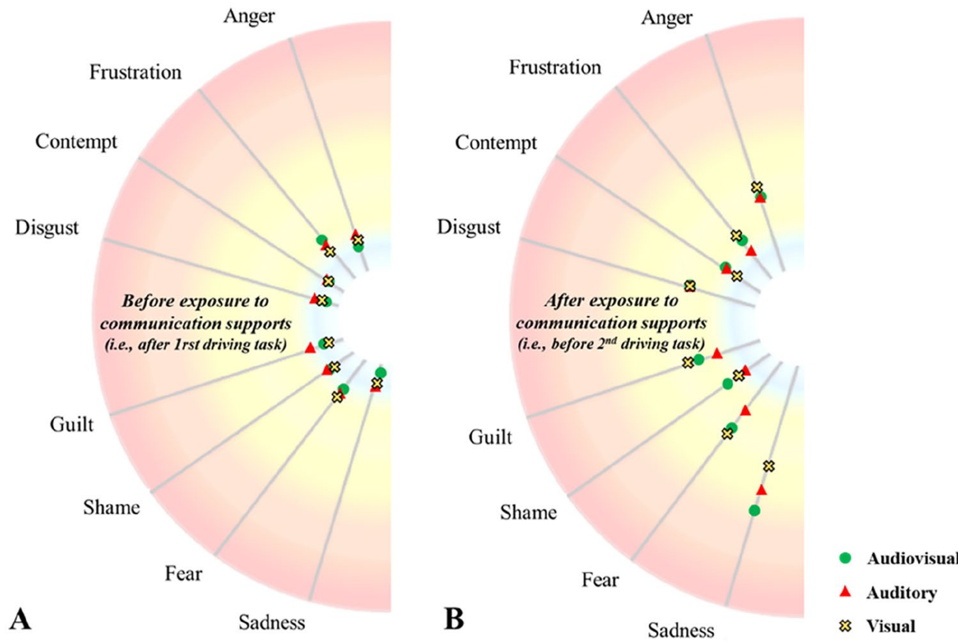

Fig. 3 Average emotional assessment at before (**a**) and after (**b**) exposure to communication supports

it has been, thus, decided not to include this situation within the following analyses of cyclist detection performances.

Additionally, results for the assessment of empathy highlighted a good reliability of the test items for each component of empathy. Standardized values of α for fantasy, empathic concern, perspective-taking and personal distress were of 0.75; 0.65; 0.69 and 0.82, respectively. No significant effect of the type of communication support was observed for the scores collected for each component of empathy [$F(2, 51) = 1.28$, $p = 0.29$ for fantasy; $F(2, 51) = 0.32$, $p = 0.73$ for empathic concern; $F(2, 51) = 1.95$, $p = 0.15$ for perspective-taking; $F(2, 51) = 0.28$, $p = 0.75$ for personal distress]. Consequently, the three groups were comparable in terms of their ability to be empathetic.

Regarding the perception of the cyclist vulnerability with participants, the scores collected from the perceived cyclist vulnerability questionnaire were particularly high (83.67 for the audiovisual group, 87.83 for the auditory group and 82.83 for the visual group). Moreover, a Kruskal–Wallis ANOVA conducted with type of support (audiovisual vs. auditory vs. visual) as a between-subjects factor revealed no significant differences between groups. Consequently, the results suggest that the message had a particular content emphasizing the cyclist vulnerability, what is crucial for a road safety communication about cyclists.

Finally, we verified that exposure to the communication supports elicited emotions. To this end, the variations before and after the exposure to the communication supports was analyzed. A significant increase of all emotional intensities studied was observed between these two stages, except for the intensity of frustration for which only trend was found ($p = 0.09$).

6.1 Analyses of emotional state while exposed to communication supports

Regarding subjective emotional state, results did not show any significant differences between groups regarding the assessment of negative emotions experienced at baseline (i.e., before performing the first driving task) [$H(2, 54) = 2.64$, $p = 0.27$ for anger; $H(2, 54) = 1.64$, $p = 0.44$ for frustration; $H(2, 54) = 2.77$, $p = 0.25$ for contempt; $H(2, 54) = 2.43$, $p = 0.30$ for disgust; $H(2, 54) = 1.88$, $p = 0.39$ for guilt; $H(2, 54) = 3.07$, $p = 0.22$ for shame; $H(2, 54) = 3.14$, $p = 0.21$ for fear; $H(2, 54) = 2.39$, $p = 0.30$ for sadness]. The intensities of negative emotions felt by the three groups were therefore comparable at baseline. Consequently, it may be assumed that participants had a comparable emotion state before starting the first driving task. No significant differences appeared between groups in the assessment of negative emotions after exposure to the safety messages [$H(2, 54) = 0.73$, $p = 0.69$ for anger; $H(2, 54) = 1.50$, $p = 0.47$ for frustration; $H(2, 54) = 0.38$, $p = 0.83$ for contempt; $H(2, 54) = 0.25$, $p = 0.88$ for disgust; $H(2, 54) = 1.35$, $p = 0.51$ for guilt; $H(2, 54) = 0.12$, $p = 0.94$ for shame; $H(2, 54) = 1.20$, $p = 0.55$ for fear; $H(2, 54) = 3.73$, $p = 0.16$ for sadness]. Consequently, the intensities of negative emotions felt by the three groups were also comparable after exposure to the communication supports (see b in Fig. 3). This result is not congruent with the modality-related intensities hypothesis.

Table 1 Summary table of means and standard deviations for the indexes recorded during the driving task before and after exposure to communication supports (only results for significant effect of the exposure to support variable are presented)

Dimension assessed	Indexes	Driving task before exposure to CS	Driving task after exposure to CS
Emotion	Pupil size (in mml)	$M = 4.96$, SD = 0.53	$M = 5.03$, SD = 0.53
Dynamism of visual scanning strategies	Number of saccades per minute	$M = 104.36$, SD = 15.20	$M = 116.10$, SD = 15.11
Dynamism of visual scanning strategies	Fixation duration (in ms)	$M = 517.74$, SD = 94.91	$M = 453.82$, SD = 72.64
Dynamism of visual scanning strategies	Speed of head movements (horizontally) (in° s^{-1})	$M = 11.16$, SD = 4.87	$M = 12.81$, SD = 5.43
Dynamism of visual scanning strategies	Speed of head movements (vertically) (in° s^{-1})	$M = 3.39$, SD = 0.96	$M = 3.62$, SD = 1.05
Information processing	1rst fixation duration (in s)	$M = 1.46$, SD = 0.53	$M = 1.28$, SD = 0.52
Behavior	Speed in key areas (in km h^{-1})	$M = 6.56$, SD = 1.14	$M = 5.88$, SD = 1.04
Behavior	Time for cyclist detection (in s)	$M = 1.35$, SD = 0.35	$M = 1.20$, SD = 0.41

CS communication supports, *M* mean, *SD* standard deviation

Results on cardiac data did not reveal any differences between groups for any of the cardiac indicators studied at baseline [$F(2, 50) = 0.10$, $p = 0.90$ for SDANN; $F(2, 50) = 2.14$, $p = 0.87$ for HR; $F(2, 50) = 0.22$, $p = 0.80$ for RMSSD; $F(2, 50) = 0.20$, $p = 0.82$ for pNN50; $F(2, 50) = 0.22$, $p = 0.80$ for SD1; $F(2, 54) = 0.19$, $p = 0.83$ for SD2; $F(2, 50) = 0.73$, $p = 0.49$ for SampEn; $H(2, 53) = 1.29$, $p = 0.52$ for LF/HF]. No significant effect of the type of support appeared between groups for any cardiac indicator after exposure to the communication supports [$F(2, 50) = 0.00$, $p = 0.99$ for SDANN; $F(2, 50) = 0.22$, $p = 0.80$ for HR; $F(2, 50) = 0.09$, $p = 0.92$ for RMSSD; $F(2, 50) = 0.07$, $p = 0.93$ for pNN50; $F(2, 50) = 0.09$, $p = 0.92$ for SD1; $F(2, 54) = 0.04$, $p = 0.96$ for SD2; $F(2, 50) = 0.72$, $p = 0.49$ for SampEn; $H(2, 53) = 0.45$, $p = 0.49$ for LF/HF]. The three groups were therefore comparable for the values recorded for all of the cardiac measures during exposure to the communication support. This result is not congruent with the intensity-related physiological pattern hypothesis.

6.2 Analyses of cyclist detection performances, ocular metrics and speed management in key areas while driving

No significant effect of the type of support for cyclist detection was found but a significant effect of exposure period [$F(1, 50) = 5.53$, $p = 0.02$, $\eta p^2 = 0.10$] and first fixation duration [$F(1, 50) = 5.52$, $p = 0.02$, $\eta p^2 = 0.10$] was observed. Both results showed lower values for the second driving task than for the first driving session (Table 1), which means that the detection of cyclists was faster and the fixation durations were lower after the exposure to the communication supports. No significant interaction was found between the effect of the exposure period and the effect of the type of support on these two measures. This set of results is partially congruent with the benefit of intensity-related messages hypothesis.

Ocular metric results showed no effect of type of support, either for pupil size or for any other index related to visual scanning strategies. However, when the effect of exposure period was studied, significant differences appeared between pre- and post-exposure to communication supports for the number of saccades per minute [$F(1, 50) = 88.35$, $p < 0.001$, $\eta p^2 = 0.64$] fixation durations [$F(1, 50) = 79.43$, $p < 0.001$, $\eta p^2 = 0.61$] and the speed of horizontal head movements [$F(1, 50) = 40.01$, $p < 0.001$, $\eta p^2 = 0.44$] and vertical head movements [$F(1, 50) = 16.26$, $p < 0.001$, $\eta p^2 = 0.25$] recorded during driving. More specifically, increasing values for the number of saccades per minute and speeds of horizontal and vertical head movements were observed, along with decreasing values in fixation duration (Table 1). This set of results is partially congruent with the benefit of intensity—related messages hypothesis.

A significant effect of exposure period was found on pupil size [$F(1, 50) = 36.26$, $p < 0.001$, $\eta p^2 = 0.42$] (Table 1) as well as a significant interaction between the effect of exposure period and the effect of the type of support on pupil size [$F(2, 50) = 6.40$, $p < 0.01$, $\eta p^2 = 0.20$]. An increase was found between pupil size recorded during the driving sessions prior to exposure to communication supports, and those measured afterwards only in participants exposed to audiovisual and visual supports. However, the period of exposure factor considered alone had no significant effect on saccadic amplitude.

Results related to speed in key areas did not show any significant effect of the type of support but highlighted a significant effect of exposure period [$F(1, 50) = 59.47$, $p < 0.001$, $\eta p^2 = 0.54$]. They revealed a decrease in speed in the driving task which followed exposure to communication supports

Table 2 Summary table of means and standard deviations for the intensities of emotions collected with the emotional wheel for the stage related to exposure to communication supports and those collected for the second driving task (only results for significant effect of the persistence of emotion variable are presented)

Intensities of emotions	Exposure to CS	Driving task after exposure to CS
Anger	$M=20.54$, SD = 17.01	$M=10.67$, SD = 13.69
Contempt	$M=9.30$, SD = 11.02	$M=6.15$, SD = 9.81
Disgust	$M=16.13$, SD = 15.14	$M=5.26$, SD = 8.79
Sadness	$M=30.31$, SD = 14.93	$M=5.72$, SD = 9.39

The higher the scores the higher the intensities felt are, and vice versa
CS Communication supports, *M* Mean, *SD* Standard deviation

($M=21.17$, SD = 1.04) compared to the speed recorded in the driving task which preceded exposure to communication supports ($M=23.62$, SD = 1.14). No significant interaction was found between the effect of the exposure phase and the effect of the type of support on this variable. This result is partially congruent with the benefit of intensity-related messages hypothesis.

6.3 Persistence of emotions after exposure to communication supports

Results revealed a significant effect of persistence of emotion only for the intensities of anger ($Z=4.41$, $p<0.001$), contempt ($Z=2.91$, $p<0.01$), disgust ($Z=4.45$, $p<0.001$) and sadness ($Z=6.07$, $p<0.001$). Means obtained highlight a decrease of the emotional intensities between the exposure to communication supports and the second driving stage as illustrated in Table 2 below. However, neither an effect of type of support, nor any significant interaction was observed.

7 Discussion

This study aimed to gain understanding of how emotions, experienced while people were exposed to road safety messages eliciting different intensities of a same negative emotional state, were subsequently able to modify their driving behavior and affect their ability to detect cyclists.

7.1 Exposure to road safety messages

Although the exposure to communication supports allowed increasing the intensity of some negative emotions suggesting the efficiency of the emotional induction, the results showed that the three supports elicited the same pattern of negative emotions in which sadness dominated (Fig. 3). This result does not allow validating the modality-related intensities hypothesis which assumed that the combination of auditory and visual modalities would elicit emotions of a higher emotional intensity than the visual or auditory channels on their own (Mastroberardino et al. 2008; Paulmann and Pell 2011; Spreckelmeyer et al. 2006). Therefore, it seems that the message delivered in a safety communication is more important than the type of communication support used to deliver it. Thus, it might be assumed that a specific safety message would be as efficient regardless the type of communication support used to deliver it: audiovisual (e.g., television), visual (e.g., posters) or auditory (e.g., radio). Another interpretation of those results might be linked with the concept of cognitive dissonance defined as a conflict between cognitions or parameters of knowledge (see Festinger 1957). As suggested by Vanderhaeger et al., detecting or controlling such dissonance can lead to discomfort, overload, embarrassment but also self-satisfaction, enjoyment, well-being or pride (Vanderhaegen and Carsten 2017). In this study, the absence of significant differences between the different supports in terms of intensity felt might also be due to a rejection of the dissonance between their bad feelings in order not to be affected by the discomfort caused by the content of the support.

The absence of significant differences arising from the type of communication support used in cardiac measurements obtained during exposure to road safety messages is not congruent with the intensity-related physiological pattern hypothesis. The emotional sets elicited were probably too close to each other in terms of subjective elicited intensity to allow observing specific cardiac variations for each group. It is also worth remembering that antagonist effects on the ANS of some negative emotions may occur with the emotional patterns elicited (see Kreibig 2010). These could erase the differences between groups, and this could explain the absence of any significant effect of the type of communication support variable in this study. Consequently, cardiac measures, or at least the cardiac indexes used in this study, might not be the best way to distinguish the sets of emotional intensities elicited in each experimental group.

7.2 Driving

Results for subjective data collected between the exposure to the safety message and the second driving task highlighted that some intensities of negative emotions (four intensities on eight collected) tended to decrease between these two stages of the experiment. The rest of the emotions that were maintained during the driving task (i.e., frustration, guilt, shame and fear) are likely to be related to driving activity itself. Indeed, driving cannot be considered as a neutral task, especially when road users have to be detected by the driver. This variation of the participants' emotional state does not allow concluding about how much time the set of emotions elicited with the safety message persisted. Further investigations have to be conducted in order to find a more accurate way to assess how long emotion lasts. A possibility would be to monitor and classify the participant's emotional state using several physiological metrics (e.g., Lee and Chung 2012).

Initially, pupil size variations were recorded in order to find out if emotion elicited by exposure to communication supports lasted throughout the driving task which followed. While subjective emotional assessment indicated no significant differences between groups, results for pupil size variations during the two driving phases showed that pupil sizes were larger during the second driving task only for groups exposed to audiovisual and visual supports. There are several explanations to these results.

First, as suggested in the introduction of the article of Partala and Surakka (2003), modality of presentation of an emotional stimulus could affect pupil size. Consequently, the larger pupil sizes observed for both the audiovisual and the visual groups after being exposed to the safety supports could be explained by the visual properties of both the audiovisual and visual supports as compared to the auditory support. Another possibility is that the increased pupil size in the audiovisual and visual group during the subsequent task was due to a recognition bias (see Goldinger and Papesh 2012; Heaver and Hutton 2011; Võ et al. 2008) In other words, seeing the cyclist during the driving stage would elicit the same physiological response than seeing the cyclist crash in the communication supports. Therefore, it is difficult in this study to clearly conclude about the meaning of pupil size variations observed in the second driving stage.

Cyclist detection performances provided very interesting information about participants' attention management while driving. Better cyclist detection performances were observed in participants exposed to the communication supports, regardless of the type of communication support used (i.e., audiovisual, auditory, visual). The shorter cyclist detection times highlighted better information processing leading to more efficient cyclist detection during the second driving task. In addition, according to Henderson and Pierce (2008), fixation durations increase with the time needed to analyze a visual scene. Consequently, the shorter first fixation durations observed in the second driving task (following exposure to communication supports) also reflected more efficient processing of cyclists due to the communication supports used to present safety messages. Nevertheless, the improvement in cyclist detection performances could also reflect a training effect.

Analysis of other metrics provided guidance for the interpretation of these results. First, fixation durations were shorter in the second driving task than in the first one. Second, the number of saccades per minute was higher and the speed of head movements recorded was greater during the second driving task than during the first one. All these results point to a more dynamic search for relevant information. Additionally, participants drove more slowly in key areas in the second driving task. This phenomenon could notably be explained by Kahneman's theoretical approach of attentional resources which suggests that performances would be impaired in double-task paradigms because of a single resource base available (Kahneman 1973). As driving requires the processing of much visual information, it is feasible that drivers slowed down to decrease the temporal density of the information (quantity of information processed by unity of time; see Rogé et al. 2004). This, in turn, would have allowed them to re-allocate more attentional resources for detecting cyclists. Given that a practice session has been set up before the first driving stage, it suggests that the combination of a dynamic search for information and decreased speed in key areas indicative of safer driving reflects an effect of the presentation of safety messages before driving rather than a training effect. The absence of significant effect of the communication supports on cyclist detection performances suggests that safety information, or at least the combination of safety information and negative emotions, is a primary factor in the ability to detect cyclists, while the intensity of emotion elicited is not.

According to Rogé et al. (2015), safety messages relating to VRUs enhanced their visibility. In contrast, eliciting negative emotions with different intensities via short film clips, without referring to road safety, does not improve motorists' ability to detect cyclists (Lafont et al. 2018). When the results of that study are considered alongside those obtained in the study, interesting possibilities for further investigation emerge. As illustrated in Fig. 4, the emotional ratings obtained on the same questionnaire in the three studies are visually comparable on the different dimensions (i.e., emotions) assessed. Note that data used for the Lafont's study (2018) reflect emotional assessment carried out after exposure to a film clip eliciting negative emotions of medium intensity (unpublished data embedded to the 2018 Lafont's thesis).

As Lafont's study (2018) observed, eliciting a pattern of negative emotions with a relatively low intensity through an audiovisual support with no reference to road safety is not sufficient to improve motorists' VRU detection abilities. In contrast, when a comparable emotional pattern is elicited along with safety information, as is the case in Rogé's study (2015) and in this research, an improvement in motorists' VRU detection abilities can be observed. Therefore, it can be concluded that emotion is indeed part of road safety communication. It is an important feature but it is not sufficient on its own to improve VRU detection abilities with car drivers. Emotion has to be combined with safety information in order to improve detection abilities. It would be interesting to investigate whether a safety message alone (i.e.,

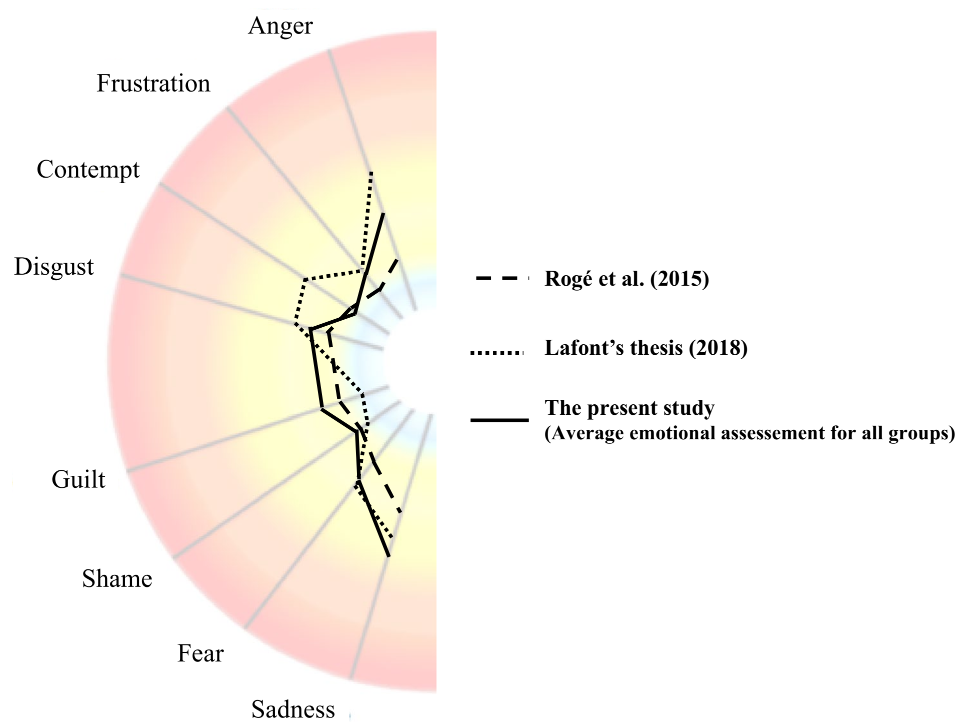

Fig. 4 Emotional assessments in three studies after exposure to communication supports (Rogé et al. 2015; this study) and short film clips (Lafont et al. 2018)

eliciting very low intensities of negative emotions) could affect motorists' VRU detection abilities. Nevertheless, precautions must be taken when designing this type of message because of the difficulty of dealing with this issue without eliciting emotions.

It is also important to stress some limitations in this study. First, the conclusions of this study rely on a specific safety message eliciting a specific emotional blend. It would be interesting to explore other messages eliciting other emotions to test those hypotheses again. Secondly, the use of different sensory modalities to elicit different intensities of emotions has to be questioned as it seems not to be the best option to succeed, at least for the safety message used. Other types of emotion elicitation might be used to succeed in inducing a same set of emotions with different intensities. For instance, playing on the context in which the participant is exposed to the communication support (e.g., watching the audiovisual support on a smartphone vs. in a movie theater). Also, a replication of this study might be interesting to assess the reliability of the data collection techniques used in this study. Finally, it has to be noted that a supplementary control group exposed to neutral road safety campaigns would have provided complementary information in order to make sure that the performance improvement is linked with the exposure to safety messages and not just the consequence of a training effect. Unfortunately, we did not manage to find such material due to the fact that road safety campaigns frequently refer to death which is a non-neutral topic (Daignault and Paquette 2010). On another hand, creating a new communication support by ourselves would have been possible. We could effectively have used some neutral videos unrelated to road safety (e.g., excerpts of an animal documentary). However, choosing this option would have created at least one confounded variable. Indeed, contrary to the other communication supports, this homemade video would have no reference to the vulnerability of some road users (the cyclists in this study). Unfortunately, highlighting the vulnerability of some road users involves showing at some point how much they are fragile, vulnerable. This, in turn, may hardly be illustrated other than with a crash or injuries. That is the reason why we chose to use a specific material in each experimental group with a same semantic content that referred to cyclist vulnerability by playing with sensory modalities to vary the intensities of the emotion elicited by each communication support.

It might also be interesting to look at the possibilities offered by this study in terms of future applications. Similarly to the study of Vanderhaegen et al., who combined cardiac and eye-tracking measurements to identify unconscious states and proposed to apply this principle to solve some driving issues (Vanderhaegen et al. 2020), certain metrics from this study might be useful for the implementation of advanced driver-assistance system (ADAS). For instance, due to the growing presence of eye-tracking measurements in cars, fixation durations, the number of saccades per minute and the speed of head movements might be used in the future to help diagnose if a driver properly saw some vulnerable road users since this metric was associated to better driving performance in this study.

8 Conclusion

Overall, this study provided a set of interesting results. First, using a combination of low-intensity negative emotions with safety messages is an efficient strategy for a successful road safety communication when the aim is to improve motorists' ability to detect cyclists. This statement is congruent with studies that suggest moving beyond highly negative emotions appeals to persuade and changes behaviors (e.g., Lewis et al. 2007; Tay and Ozanne 2002). Therefore, it might be very useful to assess the types and the intensities of negative emotions used within a media before use it in the framework of a safety campaign targeting VRUs. With this in mind, the question of the emotion assessment arises. This study suggests that using the emotional wheel, which allow the assessment of several emotions need to be further developed when the aim is to gain better understanding of an individual's emotional state. It provides an easy way to interpret the emotional assessment thanks to its visual representation of the discrete and intensity features of emotions. In addition, combining this type of emotional assessment with objective data such as VRU detection performances or indexes describing the dynamism of the visual scanning strategies allows a more thorough investigation of the effectiveness of road safety communication. We also insist on the benefit of using immersive behavioral assessments (see for example Eherenfreund-Hager et al. 2017) to get conclusions which will be more transferable to real world. Finally, the results offer interesting avenue for safety campaign designers suggesting that the type of communication support is less important than the message itself to deliver some negative emotions.

Declarations

Conflict of interest Alex Lafont declares that he has no conflict of interest. Joceline Rogé declares that she has no conflict of interest. Daniel Ndiaye declares that he has no conflict of interest. Jean-Michel Boucheix declares that he has no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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