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The power of humorous audio: exploring emotion regulation in traffic congestion through EEG-based study

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Abstract

Traffic congestion can lead to negative driving emotions, significantly increasing the likelihood of traffic accidents. Reducing negative driving emotions as a means to mitigate speeding, reckless overtaking, and aggressive driving behaviors is a viable approach. Among the potential methods, affective speech has been considered one of the most promising. However, research on humor-based affective speech interventions in the context of driving negative emotions is scarce, and the utilization of electroencephalogram (EEG) signals for emotion detection in humorous audio studies remains largely unexplored. Therefore, our study first designed a highly realistic experiment scenario to induce negative emotions experienced by drivers in congested traffic conditions. Subsequently, we collected drivers' EEG signals and subjective questionnaire ratings during the driving process. By employing one-way analysis of variance (ANOVA) and *t* tests, we analyzed the data to validate the success of our experiment in inducing negative emotions in drivers during congested road conditions and to assess the effectiveness of humorous audio in regulating drivers' negative emotions. The results indicated that humorous audio effectively alleviated drivers' negative emotions in congested road conditions, with a 145.84% increase in arousal and a 93.55% increase in valence ratings compared to control conditions. However, it should be noted that humorous audio only restored drivers' emotions to the level experienced during normal driving. Our findings offer novel insights into regulating drivers' negative emotions during congested road conditions.

Keywords Humorous audio, Emotion regulation, Congestion, Wellbeing, EEG

1 Introduction

Negative driving emotions experienced by drivers can significantly increase the likelihood of traffic accidents [1]. The repetitive, constrained nature of driving in congested road conditions [2] often leads to driver boredom [3], frustration [4], anxiety [5], anger, and other negative emotions [6], which in turn result in more frequent rear-end collisions and overtaking behaviors [7], increased lane-changing maneuvers [8], and elevated driving speeds [9], thereby raising the risk of accidents. Studies have shown that the accident rate on congested roads can be up to 24 times higher than on uncongested roads [10]. In the European Union in 2008, traffic congestion-related fatalities exceeded 25,000, with 135,000 injuries reported [11]. Therefore, regulating drivers' negative emotions during driving on congested roads holds significant importance for road safety.

In existing research, interventions targeting driver emotions have been implemented through specific tools or media, including music [12], ambient lighting [13], voice assistants [14], and different odors [15]. These interventions have been found to have cognitive,

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emotional, and behavioral effects on drivers. Currently, driver emotion interventions can be categorized into physiological and psychological approaches.

Physiological interventions primarily aim to alleviate negative emotions by altering drivers' auditory, visual, and olfactory perceptions. For example, Fakhrhosseini et al. regulated emotions by playing music [12], while Braun et al. incorporated ambient lighting inside vehicles and used a voice assistant for empathetic interaction with users [13]. Jia et al. investigated the effects of different odors on alleviating drivers' negative emotions [15].

Psychological interventions, on the other hand, target the cognitive aspect to alleviate negative emotions. They require a certain understanding of drivers' cognition to exert influence. For instance, Lu et al. reevaluated road conditions through a voice assistant, shaping drivers' optimistic attitudes toward the current road situation based on their driving psychology [14]. Mark et al. focused on reducing frustration or anger caused by negative emotions during congested road conditions by preemptively informing drivers about upcoming traffic congestion, aiming to minimize the sense of frustration. However, the results showed that preemptive information about traffic congestion was not always effective and, in some cases, it even led to increased aggressive driving behaviors [16].

Humor, as one of the important psychological interventions, is recognized for its positive effects in reducing anxiety and alleviating stress [17]. It can be utilized as a complementary tool for emotional intervention. The use of humor as an intervention in driver behavior is mainly implemented through gamified applications during driving [18] or by incorporating humorous tones and sound effects into voice assistants. However, there is limited research specifically focusing on humor-based interventions in the context of driving.

Humor is a complex cognitive process that is widely used but does not necessarily elicit laughter [19]. The assessment of humor can be achieved through the analysis of physiological signals. Many studies have confirmed the effectiveness of emotional interventions using physiological signals, such as electroencephalogram (EEG) data analysis. For example, Li et al. analyzed the impact of traffic congestion on driver's driving behavior through the analysis of EEG signals [20]. Fuseda also employed EEG analysis to examine the emotions in news broadcasts [21]. However, in the context of humor-based interventions, the impact of humor on emotions has not been investigated through the analysis of EEG signals. Assessing the intervention effect of humor-based interventions is challenging. Therefore, this study aims to measure the effect of humor-based interventions on driver emotions by combining subjective measures with electroencephalogram (EEG) data. Extensive research has demonstrated that the amplitude and power spectral density information of the α, β, δ, and θ frequency bands in EEG signals can reflect drivers' perception, attention, decision-making, motor control, and subtle emotional changes [22].

The purpose of this study is to investigate the impact of humor-based interventions on drivers' driving emotions. Our work makes two contributions. Firstly, this is the first study that utilizes a humorous speech paradigm to regulate irritability in congested road conditions, providing new insights for the design of anger management systems for road rage. Secondly, we collect electroencephalogram (EEG) data from drivers in a simulated driving environment on congested roads and analyze and examine the effects of humor-based interventions on regulating negative emotions in the brain.

2 Related works

2.1 Interventions for negative emotions in driving scenarios

There are various types of emotion regulation interventions in human-vehicle interaction. Jerry L classified interventions into cognitive interventions, relaxation interventions, behavioral interventions, and combined interventions, and roughly differentiated them based on the post-intervention effects on anger-driven driving [6]. On the other hand, Michael Braun et al. categorized emotion intervention techniques into incentive interventions, entertainment interventions, driver state displays, gamification, affective symmetry, reappraisal, and subconscious influence [13]. These intervention approaches are all based on the system's perception of the driver's emotions to implement corresponding intervention measures [23].

Braun et al. examined four emotion regulation techniques, namely Ambient Light, Visual Notification, Voice Assistant, and Empathic Assistant, to intervene in drivers' negative emotions and found that the intervention with an empathic assistant had the highest effectiveness and popularity [13]. Humorous audio, as a type of emotion regulation method with empathic content, holds great potential. Humor is a universal human behavior observed in many cultures [24], and a sense of humor is considered important for humans [25]. There are various definitions of humor: some studies define it as a subjective psychological response to comedic stimuli [26], while others suggest that humor involves the perception of stimuli as funny [27]. Some studies classify humor instead of directly defining it. For example, Neuendorf et al. categorized humor into disparagement, incongruity, arousal, and social currency based on its characteristics [28]. Caleb Warren et al. defined and differentiated three important concepts related to humor: a sense of humor, comedy, and humor appreciation. They found that conditions that elicit laughter involve simultaneity, a violation appraisal, and benign violation [29]. Despite the diverse definitions and perspectives on humor, it is widely accepted that a sense of humor can induce positive emotions and effectively alleviate negative emotions. Humor, within the context of negative emotions, can serve as an empathic tool [30], specifically in alleviating anxiety and stress [17]. Entertainment interventions such as gamification and music playback have been studied and applied to mitigate drivers' negative emotions, but humor-related entertainment interventions mainly focus on endowing voice assistants with a sense of humor [31, 32], rather than directly utilizing universally recognized Humorous audio for interventions.

2.2 Methods for emotion analysis

Emotions can be subjectively assessed using psychological questionnaires or objectively measured through the collection of electroencephalographic (EEG) physiological signals. In subjective measures of emotions, the Self-Assessment Manikin (SAM) is commonly used as a tool to directly assess emotional valence and arousal. It offers the advantages of quick assessment and ease of understanding but does not provide precise identification of specific emotions. This limitation can be addressed by using discrete models of emotions, which encompass multiple categories. Researchers often customize the specific emotion discrete model based on the context. One of the most widely known and utilized discrete emotion models is Ekman's theory of six basic emotions [33]. The Differential Emotions Scale (DES) has been employed in various studies on driving emotions. The effectiveness of subjective emotion scales is influenced by the time elapsed since the experience, with greater accuracy observed when participants complete the scales promptly after the experience [34]. Additionally, the measurement outcomes of subjective emotion scales may be influenced by individual experiences and biases [35].

The collection of EEG signals is a more rigorous method widely used in emotion detection. However, the brain's functionality is highly complex, and the neural mechanisms have not yet formed mature computational models. Additionally, during the process of collecting physiological signals, EEG signals are susceptible to various interferences. These limitations can be partially compensated for by subjective rating scales. During the collection of EEG signals, different brain regions exhibit varying functions. Among them, the frontal lobe, located at the front of the brain, is the largest area and is highly relevant to emotions. The corresponding electrode pairs are FP2-FP1, AF4-AF3, F4-F3, and F8-F7. The recognition of different emotions also relies on different EEG frequency bands. EEG can be categorized into five frequency bands: delta (0.5–4 Hz), theta (4–7 Hz), alpha (8–15 Hz), beta (16–31 Hz), and gamma (32–41 Hz) [36].

Emotion-related brain activities are reflected in different frequency bands of EEG signals. Nie et al. reported that independent features related to positive and negative emotions were primarily observed in the right occipital and parietal lobes in the alpha band, the central region in the beta band, and the left frontal and right temporal lobes in the gamma band [37]. Studies have shown that during negative emotions, there is an increase in beta and gamma power in the frontal lobe region [38]. Additionally, we need to consider the impact of fatigue on the power spectrum of EEG waves. The brain energy spectrum of a typical driver is mainly composed of low-frequency delta waves. When drivers feel fatigued or bored, the spectrum energy shifts from the low-frequency band to the high-frequency theta and alpha bands, while the power in the beta and gamma bands decreases [39].

The method of identifying emotions based on asymmetry indices derived from EEG signals has been supported by multiple studies. Huang et al. proposed the Asymmetry Space Pattern (ASP) based on EEG to detect the valence and arousal of emotions in the brain, following the assumption of emotional valence [40]. Specifically, anger emotion can be measured through the asymmetry in the alpha band of the frontal lobe [41]. In the alpha wave, activation in the left frontal lobe is associated with approach stimuli or positive emotions, while activation in the right frontal lobe is associated with withdrawal stimuli or negative emotions. By performing time–frequency analysis, the average of the asymmetry index M is calculated by subtracting the right hemisphere alpha power from the left hemisphere alpha power for each electrode pair [42]. As alpha power is inversely related to arousal level, a positive asymmetry index indicates higher visual activity in the left hemisphere, indicating the subject's ability to spontaneously suppress negative emotions. The higher the power of alpha waves in the right hemisphere, the greater the activation in the left hemisphere, indicating better regulation of negative emotions [43, 44]. The FP1-FP2 electrode pair in the alpha band can be used to identify arousal [40]. As for anger emotion, the AF4-AF3 pair exhibits greater significance [45]. Therefore, we primarily focus on the activity of alpha waves in the left and right hemispheres using the electrode pairs FP2-FP1, AF4-AF3, F4-F3, and F8-F7.

3 Methods

This stage primarily includes an introduction to the participants and the equipment, experimental design, description of the experimental procedure, and methods for data processing.

3.1 Participants

We recruited a total of 13 participants, including 8 males and 5 females. Their ages ranged from 20 to 35 years old (M = 24.92, SD = 2.38). Each participant held a valid driver's license and had at least one year of driving experience, with the longest driving experience being 8 years (M = 2.69, SD = 1.87). All participants had normal or corrected-to-normal vision and hearing. During the recruitment process, participants were required to provide confidential information such as age, gender, driving experience, and health condition. Prior to the experiment, participants signed an informed consent form, were briefed about the general procedure and risks involved in the experiment, and received instruction on relevant traffic knowledge.

3.2 Experimental equipment and driving simulation system

In this study, an open-ended driving simulation system was utilized, simulating driving screens and driving tools (Fig. 1). The driving simulation system consisted of two screens: a 27-inch screen for simulating the forward view during driving and a 15.6-inch instrument panel screen displaying driving data such as a speedometer, tachometer, and turn signal indicators. The driving tool used was the Logitech G29 driving simulator, which included a 1060° rotation feedback force steering wheel, brake pedal, and accelerator pedal. The simulation scenarios were created using SCANeRstudio 2022 software. To reduce the difficulty of driving for participants, the simulated driving followed the rules of automatic transmission and did not involve manual shifting. The audio for the simulation driving, including traffic sounds and engine noise, was provided through the built-in speakers of a laptop to enhance the realism of the driving simulation. During the experiment, we used the BioSemi64 EEG system and Ten20® Conductive Paste to collect the brain's electrical physiological signals.

In the driving scenarios, we designed three road conditions: baseline driving, non-humorous audio road, and Humorous audio road. These three roads represent the same driving route segment. The virtual route was a single-lane, two-way road with a length of approximately 8 km and a width of 3.5 m. The participants were only allowed to drive in one direction. During the simulated driving, participants were not restricted in terms of speed but were required to follow traffic rules, such as not driving in the opposite direction, crossing the shoulder, or overtaking on a single-lane road. In the baseline driving, participants did not encounter any traffic congestion. However, in the other two formal driving scenarios, participants encountered the same traffic congestion. The difference between the two formal driving scenarios was that in the non-humorous audio road

A) SCANeRstudio 2022 B) Logitech G29 C) Speed dashboard

Fig. 1 Experimental simulation system condition, participants did not receive any additional distractions, while in the humorous audio road condition, pre-recorded humorous audio clips were played when participants encountered traffic congestion.

During traffic congestion, the humorous audio clips used were primarily sourced from popular domestic stand-up comedy shows. We initially selected 50 humorous audio clips from these comedy programs based on subjective judgments. The selection criteria were based on Warren's definition of comedy humor, which included factors such as popularity, ease of understanding, and avoiding excessive length [27]. The duration of these voice clips ranged from 30 s to 2 min. We invited three experts from Zhejiang University of Technology to rate the 50 humorous audio clips. The rating process used the Likert scale to subjectively evaluate the level of humor and the impact on emotions. After the evaluation, we finalized 24 humorous audio clips, which were randomly played during traffic congestion.

3.3 Experimental procedure

This study employed a comparative experimental design. Upon arrival at the laboratory, participants were first fitted with an EEG cap and their brain signals were connected and tested by the research staff. Afterward, participants proceeded to drive along the three road routes. At the end of each route, participants were given the option to take a 3-min break and complete the ASM (Affect Self-Assessment Manikin) and DES (Differential Emotions Scale) questionnaires to assess their current emotions.

Here is the specific procedure for each driving route:

(1) 5-min baseline driving: the purpose of this stage is to familiarize participants with the driving operation and route and measure their initial emotional state.

(2) Two formal drives: before starting the drive, participants were informed about the scenario of clocking in for work. They were instructed to complete the driving task within 12 min, starting at 7:48 a.m. Their boss required them to clock in before 8:00 a.m. If participants did not reach the destination on time, it was considered a task failure, and the experiment would be repeated. The weather during the scenario was sunny, and apart from traffic congestion, no other special situations occurred. The route included three intersections, with occasional passing vehicles making turns at the first two intersections. Traffic congestion began at the third intersection. During the congestion, participants experienced situations such as stop-and-go traffic, long periods of congestion, and being overtaken by other vehicles. Approximately 5 min after the start of the congestion, participants encountered situations of being squeezed and overtaken at the intersection.

In the experiment, participants' negative emotions were partly triggered by the poor traffic conditions and partly by the urgent driving scenario. Under the time constraint, participants' frustration levels would further increase. Both in the non-humorous audio road and humorous audio road driving scenarios, participants encountered similar traffic congestion events. The duration of congestion for each driving route was around 8 min, with a few seconds of fluctuation depending on the participants' driving situation. When there were 3 min left until the timing ended, the experimenter would remind participants to pay attention to the time.

In the non-humorous audio road condition, no humorous audio clips were played. In the humorous audio road condition, when participants started experiencing traffic congestion (driving speed <5 km/h), humorous audio clips from the humor database would be played.

After completing the driving on all road conditions, a semi-structured interview will be conducted to subjectively assess the participants' emotions and explore the sources of their emotions in depth.

The entire experimental procedure is depicted in Fig. 2.

3.4 Data recording and preprocessing

Subjective emotion measurement is mainly used to complement the physiological measurements. While physiological measurements can capture objective emotions, they cannot reflect the psychological state and the reasons behind the emotions. Therefore, after each road segment of the driving task, participants are required to complete the Self-Assessment Manikin (SAM) questionnaire and the Differential Emotion Scale (DES) questionnaire.

Questionnaire completion: the SAM questionnaire utilizes a pictorial self-report method, where participants select the picture that best represents their emotional state. The DES questionnaire assesses the intensity of specific emotions through verbal descriptions, with a scale ranging from 0 (not at all) to 9 (extremely). The emotions are divided into eight categories: "irritability, excitement, anger, happiness, nervousness, confidence, fear, sadness."

Semi-structured interviews: In the semi-structured interviews, we asked the participants to recall and discuss their experiences, and we plotted the frustration curve throughout the entire congested road (Fig. 3). Further inquiries were made based on their descriptions. The interview process was documented through note-taking and audio recording.

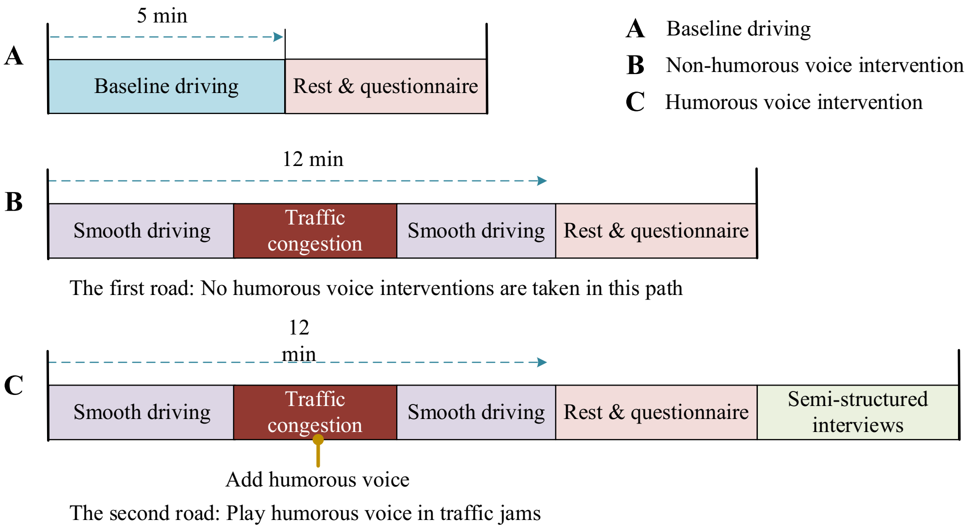

Fig. 2 Experimental flowchart of the three road conditions

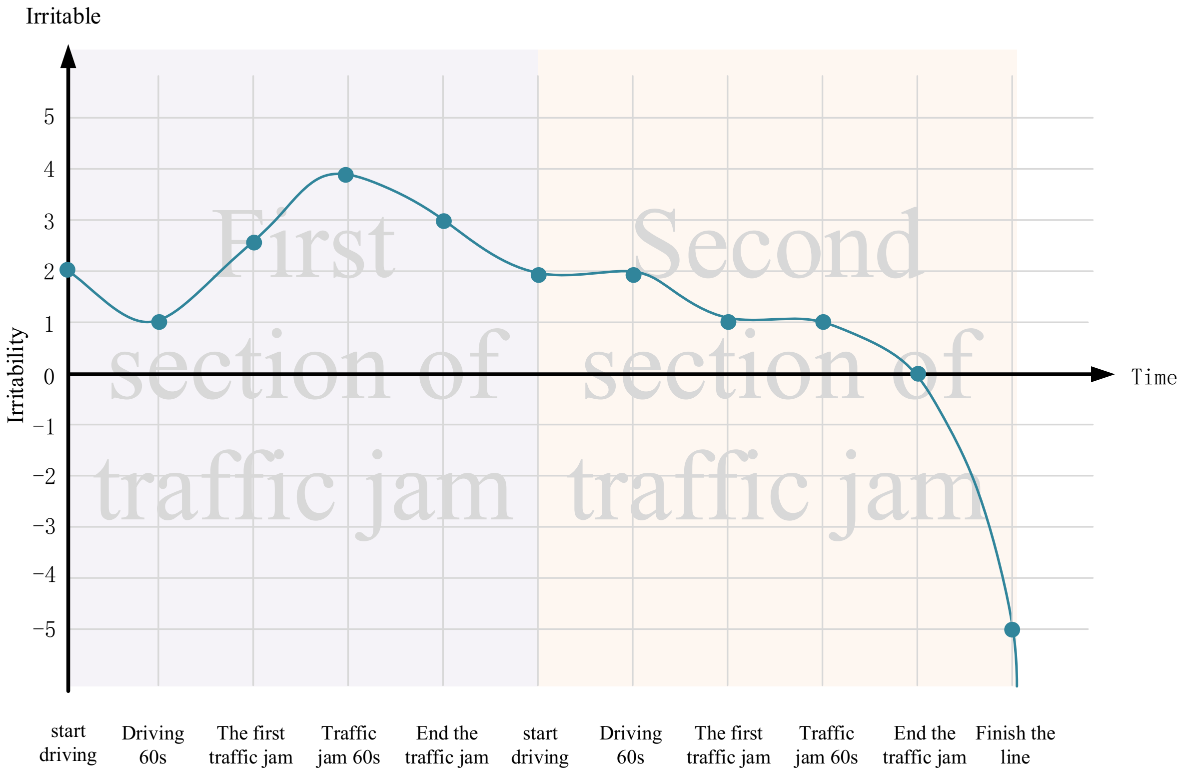

Fig. 3 The frustration curve plotted by the participant (Example 1)

3.5 Data analysis methods

After collecting the EEG data, we need to preprocess the data to reduce various interferences such as eye movements and external noises that occur during the EEG signal acquisition process. We used Matlab 2021b and EEG-lab for data processing. The “TRIGGER” channel was removed, and bandpass and powerline filters were applied to remove noise. The sampling frequency was first reduced to 128 Hz to eliminate eye artifacts and other interferences. Subsequently, frequency signals above 40 Hz were filtered out to remove irrelevant frequency components.

In E-prime software, we marked the start and end time points of traffic congestion. During the preprocessing step, the EEG data was segmented into multiple time windows. Using the start and end labels of traffic congestion, the entire road segment was divided into EEG data windows with a 60-s interval. In a congested road segment with an average duration of 480 s, we could obtain 8 EEG data windows, each lasting 10 s. EEG topographic maps were generated for these 8-time segments to observe the differences between the two different road conditions throughout the driving process and identify time segments with significant differences. Additionally, the EEG signals during the baseline driving were processed as the baseline level of EEG signals before traffic congestion.

After the data trimming process, we removed bad channels and employed the ICLable plugin to identify artifact components. Subsequently, in EEGlab, we applied a weighted interpolation method to reduce potential biases caused by the mean values. Fourier transform and wavelet transform were used for feature extraction in the frequency domain and time domain, respectively.

3.5.1 Fourier transform:

$$F(\omega) = \int_{-\infty}^{+\infty} f(t) e^{-j\omega t} dt \tag{1}$$

The equation $e^{-j\omega t} = \cos(\omega t) - j\sin(\omega t)$ represents the complex exponential function, which is a fundamental component in the Fourier transform. In this equation, $F(\omega)$ represents the frequency spectrum analysis of the original signal $f(t)$. ω is the fixed frequency at which the analysis is performed.

By analyzing the Fourier transform $F(\omega)$, we can assess the similarity between the original signal and sinusoidal waves at different frequencies. If the signal contains a significant oscillatory component with a frequency of ω1, the magnitude of (ω_1) will be relatively large, indicating the presence of that frequency in the signal. Fourier transform measures the similarity between the original signal and sinusoidal waves using F(ω).

3.5.2 Wavelet transform:

The Wavelet transform is essentially the projection of a signal onto a series of wavelet basis functions to approximate the signal. By scaling and shifting the mother wavelet, a wavelet sequence can be obtained:

$$\Psi_{\mathrm{a,b}}(t) = \frac{1}{\sqrt{a}} \cdot \frac{t-b}{a} \Psi \tag{2}$$

In the context of the wavelet transform, the scale factor a and the translation factor b are two important parameters. a and b belong to the set of real numbers (a, $b \in R$) and $a \neq 0$. These parameters are used to control the scaling and shifting of the mother wavelet. By applying continuous wavelet transform using the base wavelet Ψ, the original one-dimensional signal is transformed into a two-dimensional signal, allowing for the analysis of the signal's time–frequency characteristics.

In terms of data analysis, we employ the independent samples t test as a statistical method to analyze the differences between two groups of data.

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{(n_1-1){S_1}^2 + (n_2-1){S_2}^2}{n_1+n_2-2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \tag{3}$$

where ${S_1}^2$ and ${S_2}^2$ represent the variances of the two samples, and n_1 and n_2 are the sample sizes of the two groups. Based on the calculated t value, the significance of the differences between the two groups of data is determined by looking up the corresponding p value in a table.

4 Results

This stage primarily aims to demonstrate, through the integration of EEG signal data analysis and subjective rating scale data, the following:

(1) Whether the experiment successfully induced negative emotions in drivers during congested road situations.
(2) The effect of humorous audio on regulating drivers' emotional states during driving.

4.1 Effectiveness of negative emotion induction

In this study, the effectiveness of negative emotion induction was examined by comparing baseline driving conditions with congested road conditions. Figure 3A–D shows the EEG topographic maps generated based on video features in five frequency bands: delta, theta, alpha, beta, and gamma. In the EEG, the color blue represents low power in the corresponding frequency band and region of the brain. The darker the blue, the lower the power. On the other hand, the color red represents high power in the corresponding frequency band and region. The darker the red, the higher the power.

In Fig. 4, Column A represents the EEG map during baseline driving when the road conditions were smooth and free from congestion. The brain energy spectrum is predominantly composed of delta waves, while the other four frequency bands exhibit lower power spectra, indicating that the driver is in a calm and normal driving state.

As shown in Fig. 3A, the baseline driving EEG topographic map represents the driver's state during smooth driving. There is a significant increase in spectral energy in the Delta frequency band, while other frequency

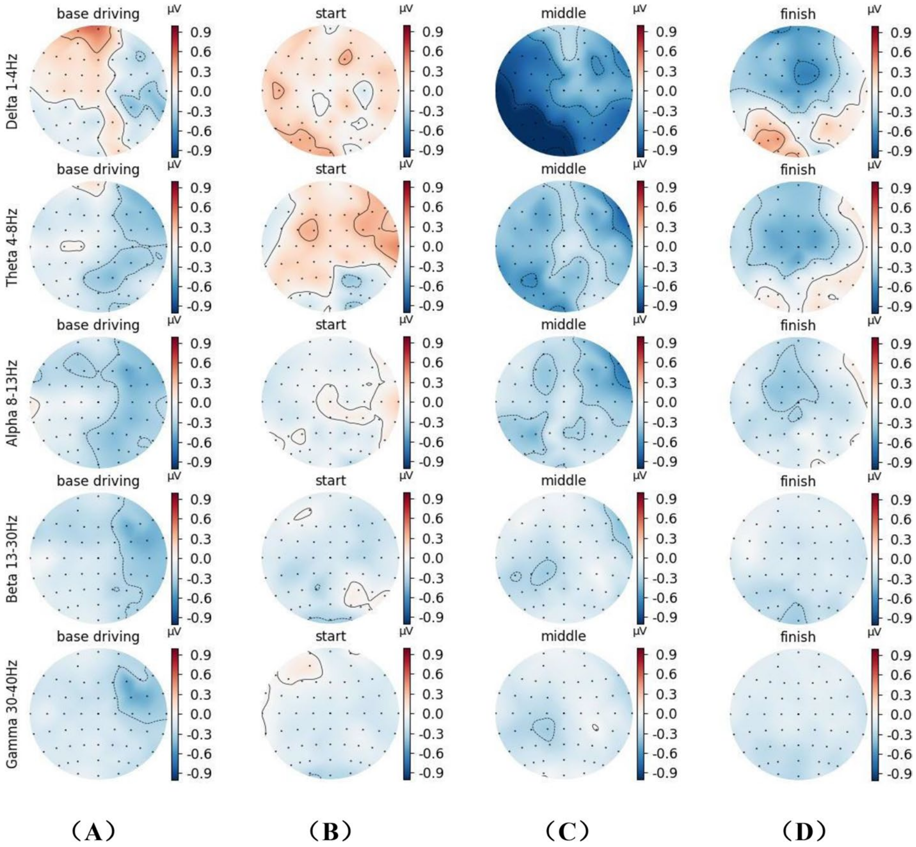

Fig. 4 Baseline driving vs. congested road EEG maps

bands show lower energy response, indicating that the driver is in a calm and alert emotional state. Figure 3B represents the onset of congestion, where there is a noticeable increase in energy in the delta, theta, and alpha frequency bands. The spectral energy gradually shifts from the low-frequency delta band to the higher-frequency theta and alpha bands, indicating the emergence of frustration and high arousal emotions in the driver. After a period of congestion, as shown in Fig. 3C, the delta and theta wave topographic maps appear predominantly in dark blue, indicating low energy, while the beta and gamma frequency bands exhibit stronger energy compared to other bands, suggesting the driver is experiencing negative and low arousal emotions. When the congestion ends, as depicted in Fig. 3D, there is a significant increase in energy in the Delta and Theta bands, highlighted by the presence of red areas. However, there is no significant improvement in the Beta and Gamma frequency bands, indicating that although the driver's arousal level has increased, it is still not as high as during the baseline driving stage, and negative emotions persist. Through the analysis of the EEG topographic maps at different driving stages, it is evident that congested road conditions can effectively elicit negative emotions in drivers, and the arousal level varies across different stages of congestion.

The conclusion drawn from the EEG analysis is supported by the results obtained from subjective rating scales. As shown in Fig. 5, a *t* test analysis revealed significant decreases in both valence and arousal levels of the drivers' emotions during congested road driving.

Specifically, the average arousal level of drivers during baseline driving was moderate ($M = 5.30$, $\mathrm{SD} = 1.25$). However, after experiencing congested road driving, the average arousal level dropped to 2.4 ($\mathrm{SD} = 0.70$). On the other hand, the average valence level during baseline driving was also moderate ($\mathrm{M} = 4.80$, $\mathrm{SD} = 1.48$), but the decrease in valence was relatively smaller compared to arousal ($M = 3.10$, $\mathrm{SD} = 1.52$).

Furthermore, it is worth noting that the standard deviation of valence showed greater variability compared to arousal, indicating a more unstable evaluation of emotional valence. These findings provide further support for the successful induction of negative emotions during congested road driving, as demonstrated by the subjective rating scales.

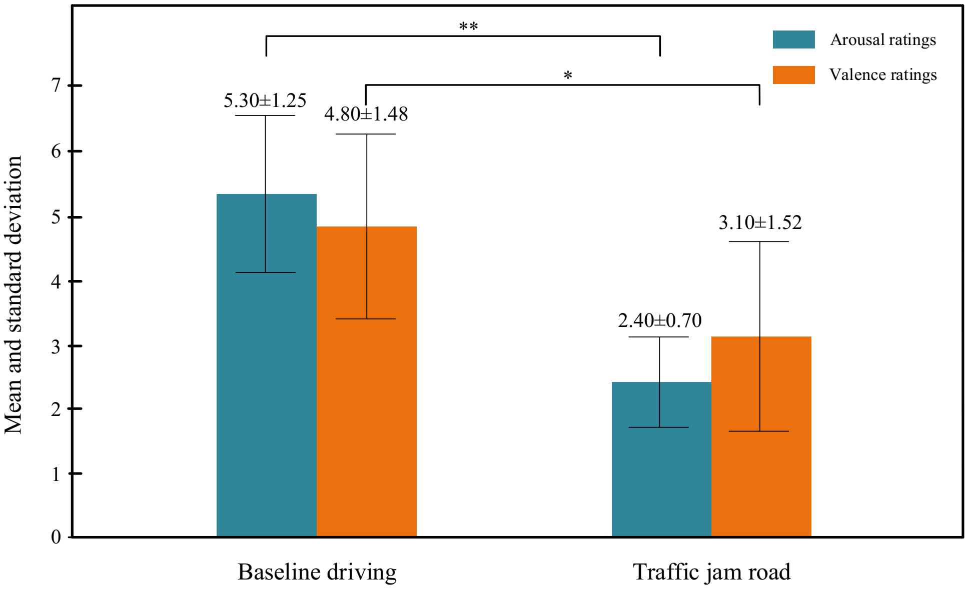

Fig. 5 Statistical graph of emotional data for baseline driving and congested road driving

Table 1 Inter-group analysis table of humorous audio road and non-humorous audio road across different EEG channels

	Humor	Not-humor	*F*	*P*
AF4-AF3	0.31 ± 0.20	0.23 ± 0.23	2.375	0.019*
F4-F3	0.24 ± 0.27	0.18 ± 0.28	1.446	0.150
F8-F7	0.37 ± 0.41	0.38 ± 0.42	− 0.082	0.935
FP2-FP1	0.21 ± 0.26	0.14 ± 0.22	1.584	0.115

* $p < 0.05$

Table 2 Variance analysis of different time periods in two roads across various EEG channels

	AF4-AF3	F4-F3	F8-F7	FP2-FP1
Baseline driving	0.22 ± 0.16	0.22 ± 0.25	0.27 ± 0.32	0.11 ± 0.13
Not-humor 0 s	0.17 ± 0.23	0.16 ± 0.42	0.16 ± 0.37	0.09 ± 0.21
Not-humor 60 s	0.24 ± 0.25	0.33 ± 0.47	0.49 ± 0.38	0.16 ± 0.23
Not-humor 120 s	0.26 ± 0.22	0.32 ± 0.50	0.44 ± 0.38	0.19 ± 0.22
Not-humor 180 s	0.20 ± 0.20	0.19 ± 0.30	0.28 ± 0.38	0.08 ± 0.13
Not-humor 240 s	0.17 ± 0.28	0.18 ± 0.46	0.34 ± 0.52	0.13 ± 0.29
Not-humor 300 s	0.29 ± 0.19	0.32 ± 0.29	0.50 ± 0.56	0.22 ± 0.27
Not-humor 360 s	0.35 ± 0.17	0.34 ± 0.23	0.54 ± 0.36	0.22 ± 0.21
Not-humor 420 s	0.17 ± 0.29	0.12 ± 0.38	0.26 ± 0.31	0.07 ± 0.21
Humor 0 s	0.26 ± 0.18	0.20 ± 0.41	0.29 ± 0.33	0.21 ± 0.22
Humor 60 s	0.34 ± 0.24	0.53 ± 0.48	0.56 ± 0.54	0.20 ± 0.16
Humor 120 s	0.31 ± 0.11	0.12 ± 0.34	0.21 ± 0.32	0.19 ± 0.21
Humor 180 s	0.51 ± 0.22	0.51 ± 0.43	0.68 ± 0.53	0.38 ± 0.53
Humor 240 s	0.38 ± 0.14	0.26 ± 0.30	0.23 ± 0.33	0.13 ± 0.18
Humor 300 s	0.29 ± 0.08	0.13 ± 0.25	0.20 ± 0.38	0.10 ± 0.12
Humor 360 s	0.41 ± 0.14	0.33 ± 0.31	0.46 ± 0.26	0.26 ± 0.23
Humor 420 s	0.33 ± 0.13	0.23 ± 0.29	0.33 ± 0.37	0.20 ± 0.20

4.2 Intervention of humorous audio on driving emotions

Table 1 presents the average values (M ± SD) of the imbalance index for humorous audio road and non-humorous audio road across different EEG channels. It can be observed from the table that the imbalance index for both roads is positive, except for the F8-F7 channel which shows an opposite effect ($F = -0.082$). In the remaining channels, the humorous audio road demonstrates better emotion regulation compared to the non-humorous audio road. However, this result is only significant ($P < 0.05$) in the AF4-AF3 channel, which is consistent with findings in other studies on anger emotions, indicating that the AF4-AF3 channel exhibits the strongest significance.

According to Table 2, in the FP2-FP1 analysis, the asymmetry index values of the non-humorous speech group showed an overall decrease followed by an increase over time. This indicates that the drivers' arousal level was initially low during the congestion process and increased as the congestion approached its end, which is consistent with the aforementioned analysis of the EEG topographic map. In contrast, in the humorous speech group, the asymmetry index showed an overall increase followed by a decrease, indicating that listening to humorous speech during driving effectively increased the arousal level and improved driving fatigue. In the AF4-AF3 analysis, the asymmetry index values of the non-humorous speech group were mostly lower than the baseline driving mean values across different

Table 3 Three-road emotional variance analysis

	Groups (M ± SD)			*F*	*p*
	Baseline	Not-humor	Humor		
Irritation	3.00 ± 2.31	6.85 ± 1.46	4.00 ± 1.83	14.370	0.000**
Excitement	2.00 ± 1.53	3.85 ± 2.61	3.08 ± 2.14	2.445	0.101
Anger	2.00 ± 1.78	6.08 ± 2.25	2.77 ± 2.13	14.331	0.000**
Happiness	2.54 ± 1.27	1.23 ± 1.09	4.92 ± 1.93	20.906	0.000**
Anxiety	3.00 ± 1.96	4.62 ± 2.40	2.77 ± 1.79	3.087	0.058
Confidence	5.08 ± 2.18	2.85 ± 1.95	4.62 ± 1.89	4.454	0.019*
Fear	1.62 ± 1.45	2.77 ± 2.62	1.77 ± 1.79	1.261	0.296
Sadness	2.08 ± 2.40	3.62 ± 3.38	1.31 ± 1.44	2.800	0.074

[*] $p < 0.05$

[**] $p < 0.01$

time periods. Additionally, with increasing time, there was an overall decreasing trend in the asymmetry index, accompanied by an increase in alpha wave energy in the right hemisphere of the brain, indicating a decrease in the drivers' ability to regulate negative emotions. On the other hand, the asymmetry index values of the humorous speech group were all higher than the baseline driving values, and with increasing time, there was an overall increasing trend in the asymmetry index, accompanied by an increase in left hemisphere brain activation. This suggests effective relief of negative emotions in drivers. To provide a more intuitive observation of the drivers' emotional states, we have plotted box plots and trend charts for each stage based on the asymmetry index of the AF4-AF3 channel as shown in Fig. 6.

After completing the driving task, the drivers rated their own emotional states. As shown in graph (a) below, the average rating of valence in the humorous audio condition was 5.90 (SD = 1.37), and the average rating of arousal was 6.00 (SD = 1.25). In contrast, in the non-humorous audio condition, the average valence rating was 2.40 (SD = 0.70), and the average arousal rating was 3.10 (SD = 1.52). Compared to the non-humorous audio condition, there was a significant improvement in both valence and arousal in the humorous audio condition, with an increase of 93.55% in valence and 145.84% in arousal. In graph (b), the valence and arousal levels of the humorous audio condition were compared to the baseline driving condition. According to *t* tests, there were no significant improvements in valence ($p = 0.32$) and arousal ($p = 0.65$) in the humorous audio condition compared to the baseline driving condition.

Upon comparing the subjective mood scale and physiological signal analysis results, we found consistency between the comparative results of the non-humorous road and humorous road groups. In the AF4-AF3 channel, overall, the imbalance index in the humorous speech road condition was significantly higher than in the non-humorous speech road condition, which aligns with the findings presented in Fig. 7a in terms of subjective data.

Regarding irritable emotions, a visual comparison was made between the drivers' self-perceived irritability on the two road segments. In Fig. 8, the *x* axis represents different time intervals during the driving, and the *y* axis represents the drivers' irritability scores. During the pre-congestion phase, the drivers' irritability did not undergo significant changes. However, there was a slight increase in irritability after the onset of congestion. The highest difference in irritability was observed during the congestion period. Although there was some relief in irritability after the congestion

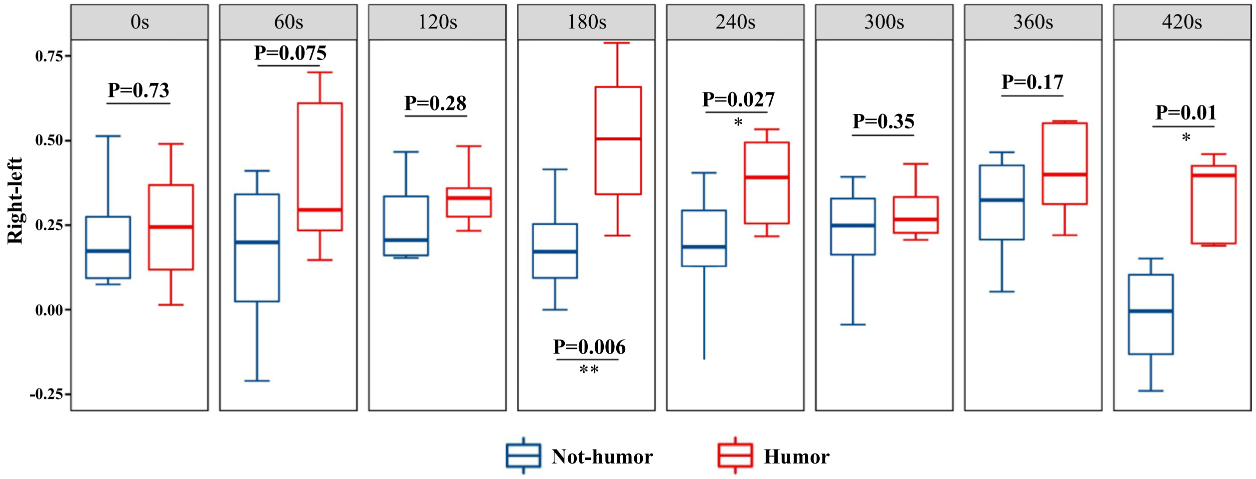

Fig. 6 Box plot of alpha waves in channel AF4-AF3

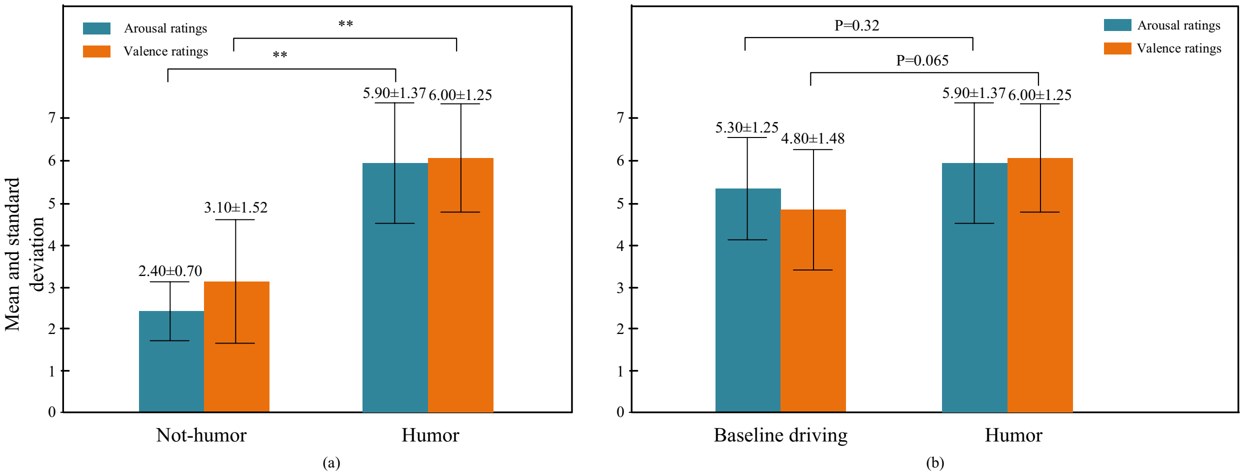

Fig. 7 Emotional data comparison across different roads

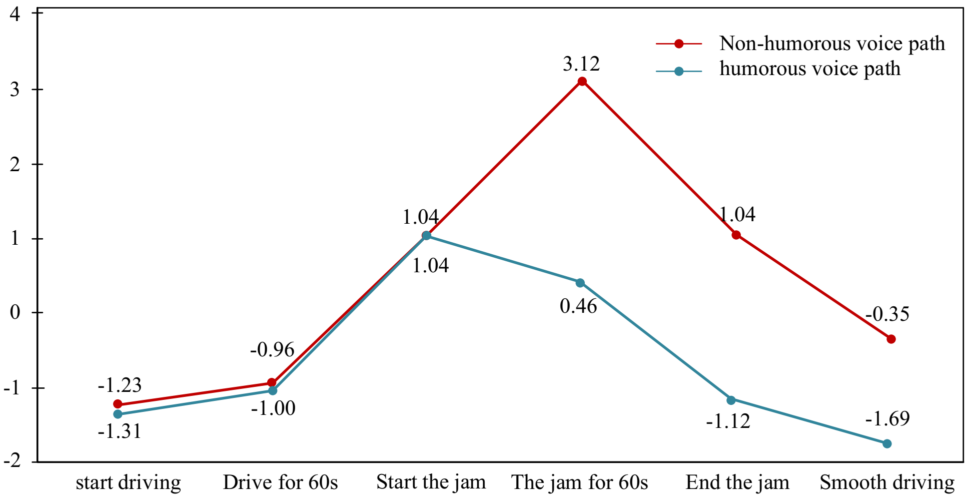

Fig. 8 Average values of irritable emotions in different time intervals

ended, the average irritability level remained higher compared to the Humorous audio road segment.

Furthermore, according to Table 3, we conducted a variance analysis on the separation of emotions, and participants showed significant differences primarily in the emotions of annoyance, anger, and joy. The significance observed in subjective rating scales differed considerably from that observed in the power of the EEG signals. This disparity can be attributed to the fact that subjective rating scales primarily capture an overall evaluation of the entire road, while EEG signals tend to measure emotions at specific moments. Additionally, participants' feelings of annoyance are subjectively and psychologically amplified.

5 Discussion

In this study, we investigated the effects of humorous audio intervention on driving emotions and the modulation of these emotions using EEG signals. The results revealed interesting findings regarding the impact of humorous audio on drivers' emotional states during traffic congestion.

5.1 The impact of humorous audio on driver emotions

Significant Enhancement in Emotional Valence: Our EEG data and questionnaire results consistently indicate that humorous audio intervention significantly improves drivers' emotional valence. In post-interviews, participants expressed a clear alleviation of their negative emotions due to the humorous audio intervention. One reason is that humorous audio directly induces positive emotions in participants. However, most of the humorous audio interventions were instantaneous, meaning that participants' emotional valence decreased after the audio concluded. Another reason is that humorous audio helps distract drivers from the negative attention focused on the congested road conditions. During the playback of humorous audio, participants occasionally and briefly forget about time constraints and the frustrating traffic situation. However, in our experiment, the real-life time pressure scenario created genuine anxiety for participants, which could not be completely eliminated by the humorous audio intervention and would resurface after the audio ended.

Recovery of emotional arousal level: according to the questionnaire responses, humorous audio can increase emotional arousal level. During congested road conditions, drivers' emotional arousal tends to be lower. Humorous audio helps restore their emotional arousal to a level similar to normal driving conditions but does not lead to excessively high emotional arousal.

5.2 The impact of humorous audio on driving safety during traffic congestion

5.2.1 Reduction in risky driving behaviors

Subjectively, the positive enhancement of emotional valence through humorous audio intervention reduced drivers' risky driving behaviors during traffic congestion, which was supported by observations during the experimental process. Objectively, humorous audio intervention decreased instances of speeding caused by frustration during traffic congestion. In the absence of humorous audio intervention, four participants honked their horns impatiently, three participants repeatedly tapped their accelerator pedals rapidly, seven participants followed closely behind the leading vehicle at intersections, not allowing other vehicles to overtake, two participants dozed off with their eyes closed during traffic congestion, and one participant continuously shook their leg. However, in the presence of humorous audio intervention, the occurrence of dozing off with closed eyes was eliminated. The behavior of honking significantly decreased, with only two instances observed among all participants. The instances of overtaking at intersections also reduced, although five participants still chose to overtake. Additionally, two participants continued to tap their accelerator pedals rapidly. Moreover, we noticed that three participants showed expressions of joy when successfully overtaking at congested intersections.

5.2.2 Driving safety resulting from emotional stability

The level of emotional arousal is relevant to driving safety on the road. However, higher emotional arousal is not necessarily better during driving. Low arousal can lead to drowsiness or lack of focus, resulting in negative and risky driving behaviors. Excessive arousal can lead to speeding and other aggressive behaviors. Therefore, moderate arousal is most conducive to driving safety. The stop-and-go nature and slow driving conditions during traffic congestion decrease drivers' emotional arousal and may induce fatigue. Since individuals have different levels of arousal, there is no precise numerical standard for measurement. However, it can be concluded that humorous audio intervention helps restore drivers' arousal levels during traffic congestion to a level similar to normal driving conditions (baseline driving) and alleviates fatigue. This finding is further supported by the EEG signal data.

We discovered additional interesting findings through semi-structured interviews. Factors that caused participants' frustration during the experiment included unclear traffic congestion ahead, time pressure, and being overtaken. Participants generally engaged in entertainment activities to alleviate the boredom of traffic congestion, such as using their phones, listening to music, or tuning into radio broadcasts, based on the actual traffic conditions. However, when humorous audio was presented as one of the options, participants unanimously reported a more pleasant driving experience with humorous audio, which did not occupy their visual and tactile senses. Comparing the interview content with the data generated consistent conclusions. Participants believed that humorous audio did not greatly enhance their emotions but effectively alleviated negative emotions associated with traffic congestion.

During the driving process, participants encountered the phenomenon of being overtaken by vehicles entering the traffic queue from side roads at intersections. Participants expressed greater anger toward this phenomenon compared to traffic congestion itself. However, some participants, when encountering the overtaking situation for the second time, followed closely behind the leading vehicle. After avoiding being overtaken, participants experienced an increase in emotional valence and arousal. We asked participants to recall the most memorable humorous audio clips, and all participants focused on two specific humorous audio clips. They found these humorous audio clips relatable, as they reflected situations encountered in their daily lives, easy to understand, and unexpected yet realistic. The humorous audio clips were also easy to remember and left a lasting impression. When discussing the issue of diverted attention caused by humorous audio, participants acknowledged that humorous audio diverted their attention from driving. However, opinions on humorous audio varied among participants. Some participants believed that humorous audio would distract them while playing music would not raise such concerns. Most participants, however, believed that even if their attention was diverted, it would not have a significant impact on driving during traffic congestion.

6 Conclusion

This study aims to investigate the regulatory effect of humorous speech on the irritability of drivers in congested traffic conditions. By inducing prolonged traffic congestion and urgent driving scenarios, the experiment successfully elicited drivers' irritability. This was manifested by a decrease in the valence and arousal dimensions of the subjective mood scale, a reduction in the irritability curve, and a phenomenon observed in the electroencephalogram (EEG) where spectral energy shifted from lower frequency bands to higher frequency bands. The study found that playing humorous speech in congested traffic significantly enhanced drivers' valence and arousal, particularly with a higher significance observed in arousal. These subjective scale results were primarily reflected in the EEG channel AF4-AF3. However, in other channels, humorous speech had a weak effect on emotional regulation, which was not statistically significant. This research demonstrates the positive regulatory effect of humorous speech on irritability in congested traffic and reduces the risk of dangerous behaviors triggered by road rage in drivers. This work establishes a foundation for future studies comparing the emotional regulation effects of humorous speech with positive music in traffic contexts.

Our experiment aimed to simulate real-life traffic congestion as closely as possible, but it also had inherent limitations. In terms of the age and gender distribution of the participants, most of them were young and rule-abiding drivers, and we cannot generalize their behaviors in congested traffic to the entire population across different age groups and personalities. Driving behavior is also influenced by driving experience [46], and the limited driving experience of our study sample restricts the generalizability of the research findings.

The audience for humorous audio is also limited, as different age groups have varying preferences for types of humor. Therefore, the humorous audio clips we prepared aimed to be popular and enjoyable for different age groups. However, we neglected the influence of factors such as age, gender, and personality on the level of enjoyment of humorous audio in this study.

Furthermore, our simulated driving may not fully reflect real-world situations. Although we tried to capture the general aspects of congested road conditions, the reality of traffic congestion is highly complex, and it is impossible to account for all situations. On the other hand, although our scenario prompt emphasized that participants must reach their destination within a specified time, it may not fully induce the sense of urgency experienced by participants in real-life situations.

In future research, it would be beneficial to consider in more detail the influence of different age groups, genders, and personality traits on driving behavior and preferences for humorous audio. Using more realistic driving simulators to simulate congested traffic conditions would provide a better understanding and study of driving behavior in real traffic scenarios. Additionally, incorporating more contextual factors can help investigate the influence of different situational factors on driving behavior.

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Authors' contributions

Y. Wang and X. Liu conceived the study and implemented the method. K. He and H. Zhang were responsible for data collection and processing. Y. Wang ran the experiment and wrote the first draft of the manuscript. L. Zhang supervised the work and revised the first draft with F. Hu and B. Xing. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to copyright protection but are available from the corresponding author upon reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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