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Fear-evoked stimuli in social and non-social domains: comparative effects on electrophysiological processes

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Abstract: Fear is a vital survival mechanism across species, triggering responses to threats and aiding in navigating dangerous environments. In humans, it plays a key role in risk assessment and decision-making, contributing to adaptive behaviour and survival. Emotional well-being and inform strategies can be enhanced for managing fear-related disorders by understanding fear's neural processing through fear-evoked stimuli. This study aimed to compare the effects of social (human mutilation) and non-social (wild animals) fear-evoked stimuli on the human brain using the event-related potential (ERP) technique. Thirty-eight participants of mixed gender and ethnicity underwent ERP assessments while being exposed to images of mutilation and wild animals alongside neutral geometric images. Brain activity was measured using a 128 HydroCel Geodesic Sensor Net, focusing on the N200 component, indicative of emotional processing. The analysis revealed that social fear-evoked stimuli (human mutilation images) elicited greater electrophysiological responses in most brain areas than non-social stimuli (wild animal images). This finding suggests that stimuli related to social fears have a greater impact on the brain than non-social fears, likely due to humans' inherent empathy for one another. The gender factor may interfere with this emotional fear processing. It highlights the critical role of social context in fear response. It suggests that understanding these dynamics can guide more effective treatments for anxiety and phobias, opening avenues for further exploration into how psychological interventions influence fear reactions.

Keywords: Event-related potentials; N200; Fear-evoked stimuli

1.0 INTRODUCTION

Fear plays a crucial role in both animal and human survival. Fear triggers the fight-or-flight response in the animal kingdom, allowing creatures to react swiftly to potential threats. Fear helps animals avoid danger, survive predators, and navigate their environment safely. A primal instinct ensures their survival by prompting caution and alertness. Fear has been integral to human survival. It alerts people to potential risks, prompting them to take precautions and avoid harm. It

is a natural response that has helped humans navigate dangerous situations, evade threats, and adapt to changing environments. Fear is an adaptive response that influences how individuals navigate their lives and their challenges. In many situations, overcoming or managing fear can allow for better decision-making, risk assessment, and, ultimately, greater chances of survival (Battaglia, 2022).

Fear-evoking stimuli can vary greatly in nature, from non-social to social threats. Non-social threats include situations where there is a direct or indirect risk of harm to one's physical or psychological well-being, such as encountering a dangerous animal (Qiasvand et al., 2022). Non-social threats typically activate the brain's fear circuitry, including the amygdala. This activation triggers the release of stress hormones like cortisol and adrenaline, preparing the body for a fight-or-flight response (Russell & Lightman, 2019).

More specifically, an individual or group of people can cause any direct or indirect risk of harm to one's physical or psychological well-being, which we call social threats (Grogans et al., 2023). These include negative behaviours such as hurting with dangerous objects that can evoke fear responses among victims. Social threats activate brain regions involved in social cognition and emotion regulation, such as the ventromedial prefrontal cortex and the anterior cingulate cortex (Giotakos, 2020). These situations can also trigger the release of stress hormones and elicit feelings of anxiety and social discomfort (Juruena et al., 2020). Thus, different natures of fear-evoking stimuli can encompass a broad range of experiences, each with its unique effects on the brain and emotion processing. Understanding these processes can inform therapeutic interventions aimed at reducing excessive fear and anxiety responses.

Gender is a crucial factor influencing various aspects of emotion processing, including perception, expression, experience, and regulation (Nolen-Hoeksema, 2012). In emotion recognition, research suggests that females may, on average, outperform males in tasks related to expressions of emotion (Pang et al., 2023). This difference may be influenced by socialization, with females often receiving more encouragement to be empathetic and attentive to others' emotions.

Gender norms and socialization can shape how individuals express emotions (Samulowitz et al., 2018). Masculinity may discourage males from displaying their actual emotions openly, leading them to mask or suppress certain emotions. In contrast, females may feel more social permission to express a wider range of emotions, including sadness and vulnerability. Studies have shown differences in brain structure and function between males and females, particularly in regions involved in emotion processing (Peper et al., 2020), that may contribute to variations in emotional responses and regulation strategies.

In the event-related potential (ERP) technique, the 'fear-evoked stimuli' are used as stimuli or triggers that elicit fear responses (Zheng et al., 2018). Neuroscientific data reports that several brain regions and circuits process fear-evoking stimuli (Sengupta et al., 2018). However, these findings derive from both human and animal models and do not give attention to the different natures of fear-evoked stimuli that may affect brain processing. Knowing the various types of fear-evoked stimuli helps to navigate potentially dangerous situations, manage fears, make better decisions, communicate effectively, and work towards overcoming phobias or anxiety. Recognizing the specific stimuli that evoke fear can enhance emotional well-being through managing fears more effectively.

This awareness will help develop strategies to overcome or cope with those fears. In addition, the influence of gender in emotional fear processing was given attention in this study to understand the emotion comprehensively. Therefore, this study aims to compare the effects of social (human mutilation) and non-social (wild animals) fear-evoked stimuli on brain activity and investigate how gender influences these responses.

2.0 MATERIALS AND METHODS

2.1 Research design and participants

This study used the ERP technique that measures brain activity indicated by the tiny voltage fluctuations (i.e., electroencephalography or EEG) in the brain that occur in response to specific visual stimuli (Kappenman et al., 2021).

Table 1. Inclusion and exclusion criteria of participants

Inclusion criteria: ▪ Young adult (18-40 years old) ▪ Right-handed ▪ Normal or corrected to normal vision
Exclusion criteria: • Lifetime history of a major medical disorder (neurological, hepatic or cardiovascular) • Seizures (including drug-related seizures) • Using medication for psychiatric disorders

We recruited an equal proportion of males and females (N = 38), with the right-handed participants exhibiting dominance. The average age of male and female participants was 29 (±10.4) years. The total number of participants was 38, of which 29 were Malay, eight were Chinese, and only one was Indian. The total participants consisted of 26 undergraduate students and 12 university employees. Participants' ages ranged from 18 to 40 years old. The inclusion and exclusion criteria are depicted in **Table 1**.

2.2 Research procedure

Participants were recruited through convenient sampling after being informed about the study via social media. We provided participants with detailed information about the procedures conducted at the Hospital Universiti Sains Malaysia's Neuroscience Laboratory before they consented to the study. The study protocol has received approval from the ethical committee board (protocol approval: USM/JEPeM/22080525).

In the experiments, people were given a 128-HydroCel Geodesic Sensor Net to wear to record their emotional and cognitive processing while they looked at pictures. The ERP presented a series of fear-evoked images, such as mutilation and wild animals, as a target image, and neutral images (geometries) as a standard (non-target) image. These images were projected from a computer screen connected to a NetAmps 300 amplifier with a high input impedance to capture EEG brainwaves. **Figure 1** illustrates the study's ERP procedure. Image presentation followed the odd-ball paradigm principle, in which deviant stimuli (standard images) occasionally interrupt repetitive stimuli (target images). We conducted 200 trials, randomly distributing three repetitions in each category.

The Severity Measure for Specific Phobia-Adult Scale (SMSP) was used to control the influence of phobia (towards specific situations) that might interfere with participants' emotional reaction to the visual presentation during event-related potential. The items of the scale ask about thoughts, feelings, and behaviours that participants may have had in a variety of situations, i.e., (1) driving, flying, tunnels, bridges, or enclosed spaces; (2) animal or insects; (3) heights, storms, or water; (4) blood, needles, or injections; (5) choking or vomiting. The SMSP is a tool comprised of ten items (maximum scores = 40; lowest scores = 0) designed to determine the severity of phobia in individuals aged 18 years and above (American Psychiatric Association, 2013).

The SMSP displays a high level of internal consistency, with a Cronbach's alpha value of 0.93 (MacLeod et al., 2022). All participants, regardless of sex difference, indicated no significant differences in SMSP scores [t(36) = 0.045; p = 0.96]. The SMSP was low for both sexes, i.e., males with a mean 19.42 (±11.54) and females with a mean 19.57 (±10.8).

2.3 Fear-evoked stimulus for ERP

Standard images of fear evoked from the International Affective Picture System (IAPS) were used as target stimuli. The IAPS assigns numerical values (mean and standard deviation) for specific emotional domains (i.e., valence and arousal) to each image based on the emotions they elicit (Bradley & Lang, 2017). We classified the images (stimuli) used in this study into three categories as follows:

2.3.1 Target stimulus 1 (odd-ball stimulus 1): fear-evoked images from the social domain

For this category, we used images of mutilated bodies (humans) to evoke a feeling of fear (IAPS image codes: 3030, 3059, 3064, 3068, 3071, 3130, 3131, 3225). From a series of images listed under the "mutilation" category in IAPS, only eight images with a normative value of arousal greater than six (classified as high arousal) and a normative value of valence less than five (classified as low valence) were selected (Lang et al., 1997). This type of image represents 15% of the total 200 trials (**Figure 1**).

To determine the content validity of the images, three psychologists evaluated the emotional content of the images by using the following options: 1 = not relevant, 2 = somewhat relevant, 3 = quite relevant (given as X), and 4 = highly relevant (given as X) (Davis, 1992). Each image was assessed using the Individual Content Validity Index (I-CVI) based on scores of 3 and 4 rated by each evaluator. Therefore, the value of I-CVI was calculated as follows: X (score of 3 or 4) divided by the number of evaluators. The final analysis revealed that all eight images have an I-CVI score of one, an acceptable value for determining content validity.

2.3.2 Target stimulus 2 (odd-ball stimulus 2): fear-evoked images from non-social domain

For this category, we used images of non-human animals (i.e., wild animals) to evoke a feeling of fear (IAPS image code: 1304, 1321, 1525, 1726, 1932, 1200, 1033, 1050). From a series of images listed under the "animal" category in IAPS, only wild animal images with a normative value of arousal greater than six (classified

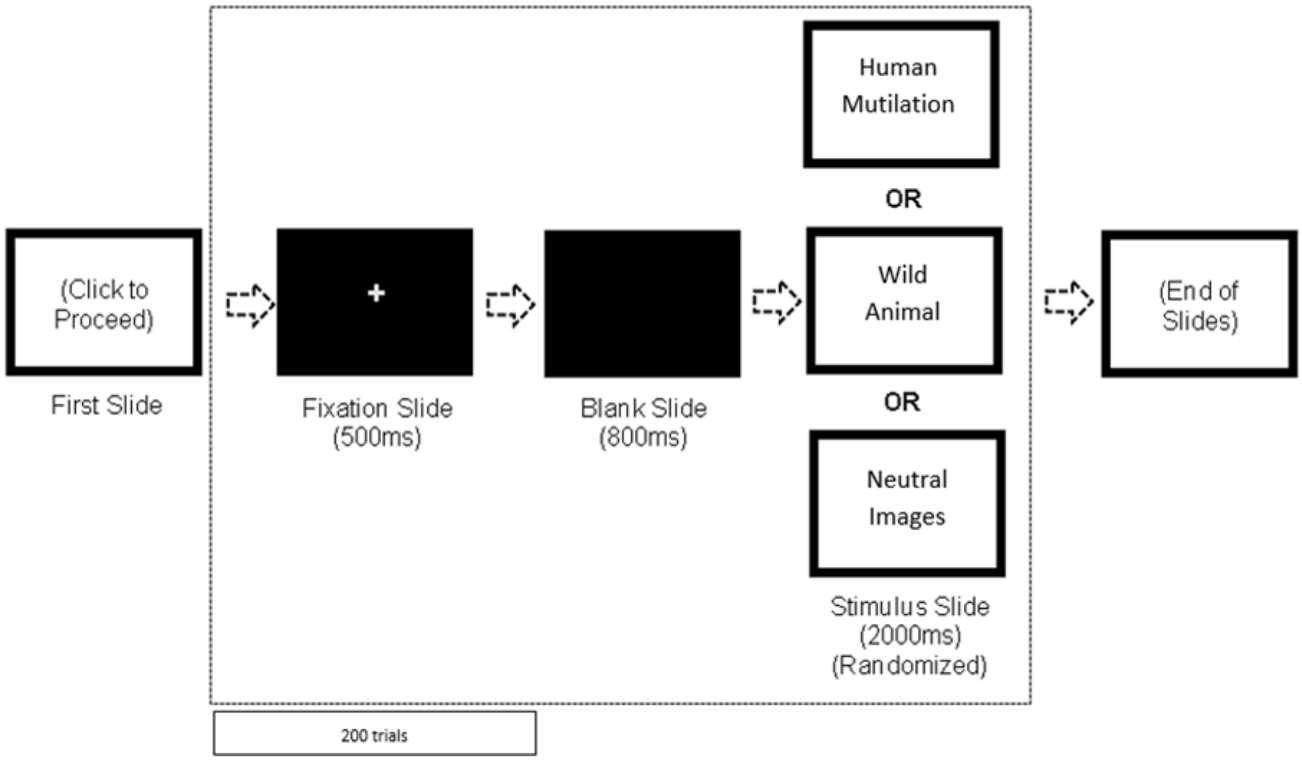


Figure 1. Experimental procedure of ERP.

as high arousal) and a normative value of valence less than five (classified as low valence) were selected (Lang et al., 1997). These criteria were fixed to be similar to the criteria in A above to standardize the emotional properties of all images (A and B).

This strategy is important to control the arousal and valence variations of the images that can be a source of bias in participants' reactions to the visual stimulus. This strategy is also meant to ensure that the electrophysiological reaction towards the different categories of images is solely due to the different nature of the image and no other factors. From this criteria, eight images were randomly selected and later multiplied four times to represent 15% of the trial from the total of 200 trials (**Figure 1**). A similar procedure (in A) was carried out to determine the content validity of the images. All images were found to have acceptable I-CVIs.

2.3.3 Non-target stimulus: neutral images

For this category, neutral geometry images were used, representing 70% of the total 200 trials (**Figure 1**). Geometry has been widely used as a neutral stimulus, as this image evokes minimal emotion (Chin & Yusoff, 2023; Yusoff et al., 2023). Neutral stimuli are often included in the visual odd-ball paradigm to serve as a baseline or control condition for the odd-ball stimuli and are typically non-task-relevant. They are distinct from the odd-ball stimuli but are designed to be emotionally or cognitively neutral. Neutral images can be a series of standard images presented repetitively and occasionally interrupted by deviant stimuli (target images).

2.4 Data extraction and analysis

Based on the international 10/20 system, the ERP data was recorded with an Ag/AgCl electrode-plated carbon pellet surrounded by a sponge and connected with a 1-meter-long insulated lead wire to a hypertronics-compatible, gold-plated pin. The scalp sites in the following five brain regions were selected for data analysis: fronto-parietal (Fp1, Fp2), frontal (F3, F4, F7, F8, Fz), central (C3, C4, Cz), temporal (T3, T4, T5, T6), and occipital (O1, O2).

Before statistical analysis, standard procedures were used to extract raw ERP data into specific components. The raw EEG brain waves were filtered based on the 0.3-30 Hz range to remove noise from electrical systems or muscle movement. By locking it at 200 milliseconds before the stimulus's onset and 1000 milliseconds after its initiation, segmentation with a 45-millisecond offset was possible. Following that, artefact identification was carried out, as was the removal of ocular artefacts such as blinking and eye movement. Bad channels (approximately 20% of all recordings across all

segments) were interpolated using the signal provided by the adjacent good electrodes. To improve the signal-to-noise ratio, the waveform was then separately averaged. The waveform data was converted into a 10-20 EEG montage and baseline adjusted. The data was averaged and merged before being turned into numerical data for SPSS analysis.

In the present study, we focused on the ERP component of the N200 since it is one of the most important components of information processing and visual cognition (Nunez et al., 2019; Zhou et al., 2020). Using the IBM SPSS Statistics software version 27, an analysis of variance for repeated measures design was undertaken to determine how the different nature of the visual fear-evoked stimulus (i.e., within-subject effects: mutilation in humans, wild animals and neutral images) affected N200 amplitudes at selected brain regions. In addition, we also examined the between subjects' effects, i.e., the different effect of participants' genders (males and females) on their electrophysiological modulation. The degree of freedom (df) was adjusted when the spherical assumption was violated. In this case, Epsilon Huynh-Feldt was reported as a new degree.

3.0 RESULTS

The N200 ERP component captured within the time window between 200 and 300 milliseconds was extracted from the specific brain areas, i.e., frontoparietal, frontal, central, parietal, temporal, and occipital. A repeated measures ANOVA was used to determine the effect of different types of fear-evoked stimulus on the electrophysiological process as reflected by the N200 amplitude.

With the exception of parietal [$F(2, 2) = 3.08$, $p = 0.072$, $\eta 2 = 0.79$] and central areas [$F(2, 2) = 20.774$, $p = 0.31$, $\eta 2 = 0.102$], the main effect was statistically significant in most of the brain areas, i.e., frontoparietal [$F(2, 2) = 11.87$, $p = 0.0$, $\eta 2 = 0.24$], frontal [$F(2, 2) = 45.32$, $p = 0.0$, $\eta 2 = 0.55$], temporal [$F(2, 2) = 10.35$, $p = <0.01$, $\eta 2 = 0.22$] and occipital [$F(2, 2) = 21.13$, $p = <0.01$, $\eta 2 = 0.37$].

The Bonferroni comparison method revealed that stimuli depicting human mutilation activated greater electrophysiological processes than those involving wild animals, particularly in the frontoparietal, temporal, and occipital brain regions. However, the pattern is slightly different for the frontal area, where the wild animal stimulus activated the electrophysiological process more than human mutilation. Meanwhile, there is no significant difference between human mutilation and wild animals in central and parietal areas (**Table 2**).

Table 2. The N200 amplitude (μv) in various brain regions, a pairwise comparison between social versus non-social stimulus

Brain region	Social stimulus (mutilation)	Non-social stimulus (wild animal)	Mean difference (standard error)	95% CI
Fronto-parietal[1]	4.5 ± 3.1	1.6 ± 1.2	2.9 (0.5)	1.6 – 4.2
Frontal[1]	1.7 ± 0.9	4.3 ± 2.0	2.6 (0.3)	1.7 – 3.4
Central	3.0 ± 1.8	2.7 ± 1.0	0.4 (0.3)	-0.99 – 0.2
Temporal[2]	3.8 ± 2.0	2.0 ± 1.7	1.8 (0.4)	0.98 – 2.6
Occipital[2]	2.9 ± 2.7	1.4 ± 1.5	1.5 (0.4)	0.5 – 2.6
Parietal	2.1 ± 1.5	2.2 ± 1.8	0.1 (0.3)	0.82 – 0.56

[1]p <0.001; [2]p <0.01; unit in Microvolt (μv).

Both males and females revealed similar patterns of emotional fear processing, with social stimuli (mutilation) stimulating the electrophysiological process more than non-social stimuli (wild animal) or neutral stimuli (**Figure 2 and 3**). However, the source localization of the N200 ERP component revealed differences in the Broadmann area (BA) and location between females and males. This difference can be seen in both stimuli (**Figures 4 and 5**).

4.0 DISCUSSIONS

The study revealed that social stimuli, specifically images of human mutilation, triggered more substantial electrophysiological responses across most brain regions compared to non-social stimuli, such as images of wild animals. This finding indicates that social contexts significantly influence brain activity, eliciting stronger fear-related emotional reactions than those evoked by non-social domains.

The perception of mutilation carries additional layers of fear due to its implications within human societies. In contrast, witnessing wild animals may evoke a fear response rooted in a primal instinct for self-preservation and a recognition of potential danger from predatory animals or environmental hazards.

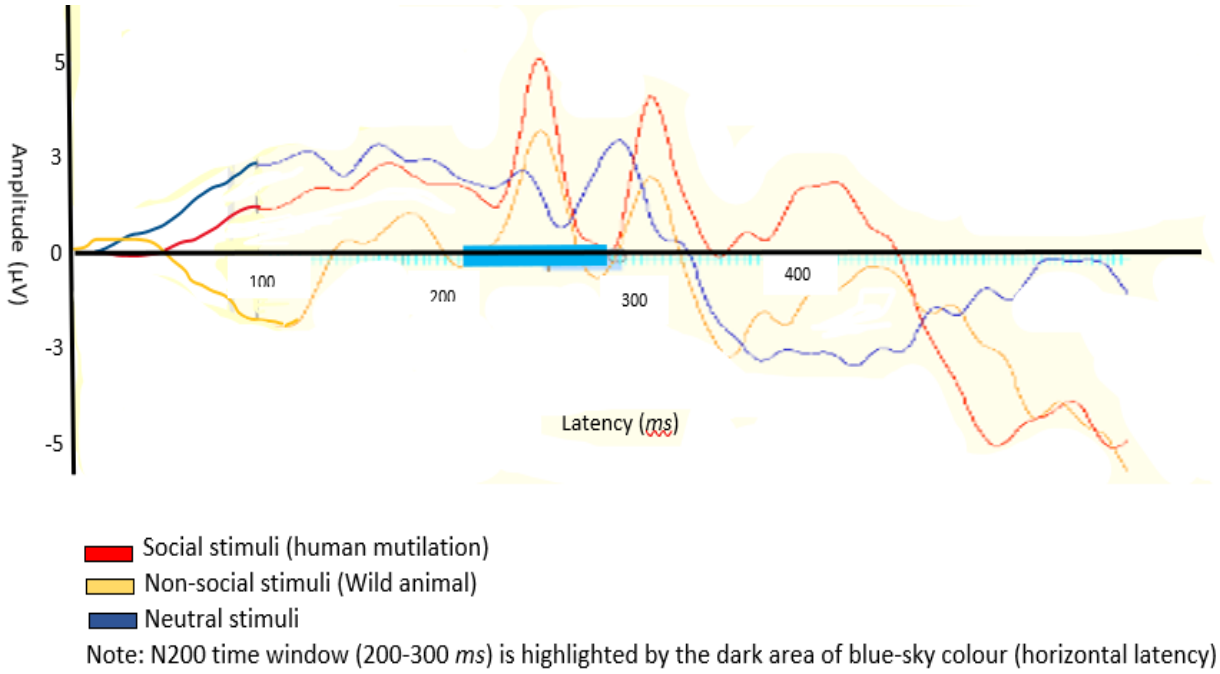


Figure 2. The difference of brainwave patterns in social (human mutilation), non-social (wild animal) and neutral stimuli in females at the central frontal area (electrode Fz).

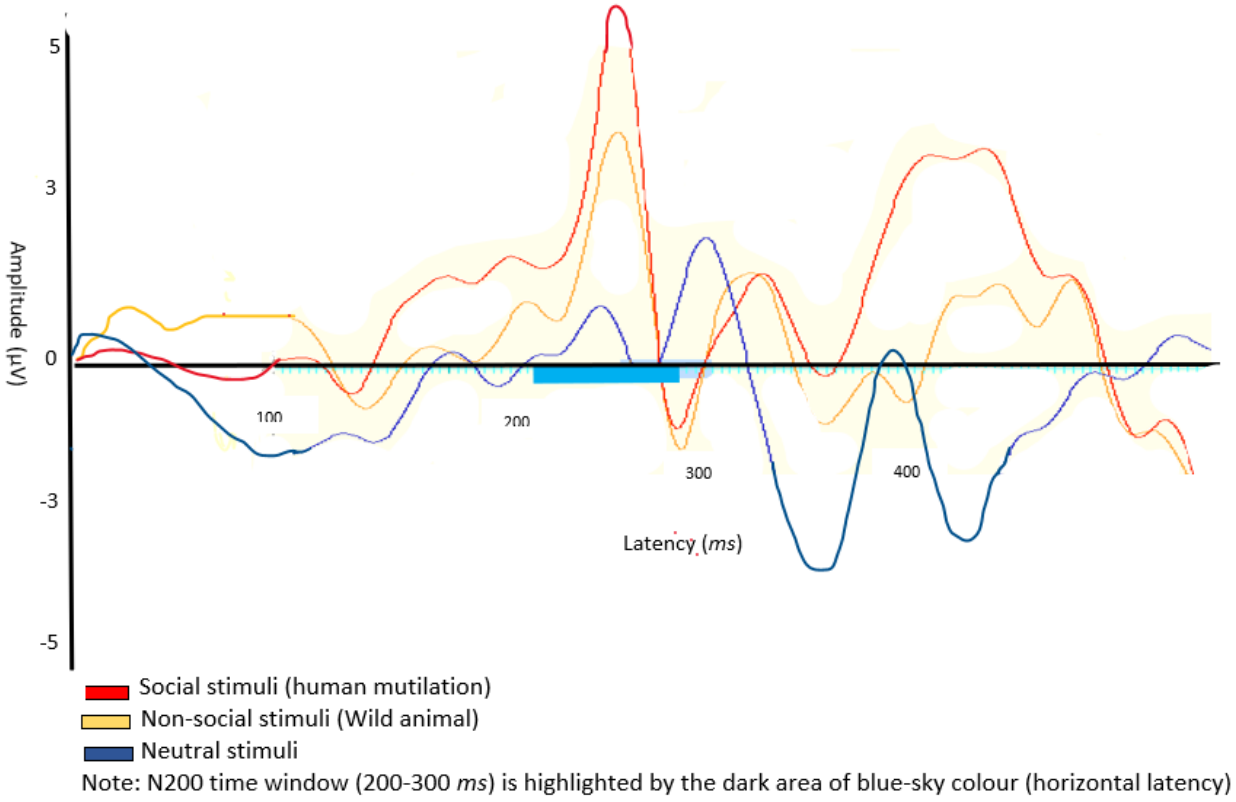
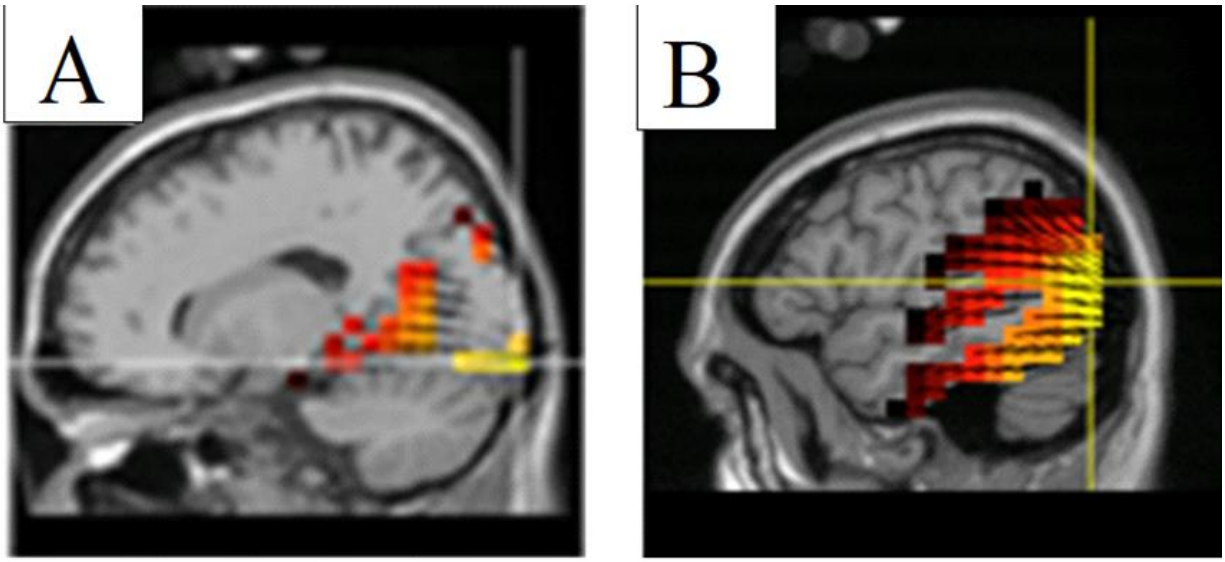
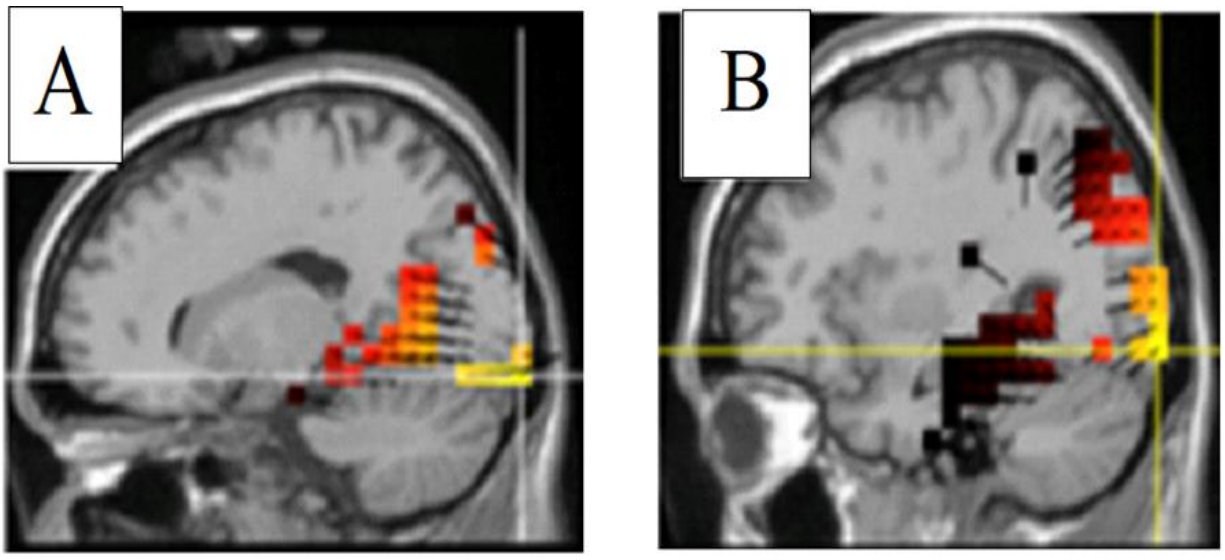


Figure 3. The difference of the brainwave patterns in social (human mutilation), non-social (wild animal), and neutral stimuli in males at the central frontal area (electrode Fz).



Descriptions:
Female (A): Location -17, -102, -13; Broadmann Area 17
Male (B): Location 53, -74, 8; Broadmann Area 39

Figure 4. Localization of N200 fear emotional processing in females and males in response to social stimuli (human mutilation) (viewed from the sagittal side).



Descriptions:
Female (A): Location 11, -88,1; Broadmann Area 17
Male (B): Location 53, -67, -13; Broadmann Area 37

Figure 5. Localization of N200 fear emotional processing in females and males in response to non-social stimuli (wild animal) (viewed from the sagittal side).

When humans witness mutilation in other humans, there is often a strong empathetic response due to the ability to identify with the victim and imagine oneself in a similar situation. This empathetic response can intensify the fear experienced (Jeon & Shin, 2011; Rymarczyk et al., 2016), especially when witnessing human mutilation. On the other hand, witnessing wild animals may evoke fear more from a sense of threat to one's safety or a general discomfort at seeing suffering in other creatures than from direct identification with the victim.

Another argument is that humans may perceive threats from other humans differently than from wild animals. Human mutilation may evoke fear not only due to the immediate threat to physical safety but also because of the potential for social disruption, loss of trust, or broader implications for society. In contrast, witnessing wild animals may primarily trigger fear as a response to the animal's potential physical harm or danger.

This study has provided some brain anatomical evidence (location and Broadmann area data) that may explain the effect of gender on fear's electrophysiological processing. Evolutionary theories suggest that males and females may have developed different adaptive responses to threats and fear-inducing stimuli based on their roles in ancestral environments (Hyde, 2014). These differences could manifest in modern-day responses to fear.

Neurological studies have shown differences in brain structure and function between males and females, particularly in areas related to emotion processing, which may contribute to variations in fear response (Grabowska, 2017). Several other reasons might explain the variation of emotion in males and females. First, the hormonal factor - its fluctuation - can influence emotional reactivity and response to fear-inducing stimuli, especially among females (Tang & Graham, 2020). Secondly, psychological and sociocultural factors should also be considered when explaining the emotional processing variation in males and females (Hyde & Mezulis, 2020).

Societal norms and expectations may influence how individuals of different genders express and respond to certain emotions, such as fear. For example, stereotypes about masculinity might discourage males from displaying fear openly. This situation may also influence their coping strategies to manage their emotional experiences. Males and females may employ different coping strategies in response to fear or stress (Smith et al., 2021), which could impact their observable responses to fear-evoking stimuli.

Understanding and identifying specific fear-evoked stimuli are pivotal for survival and play a significant role in shaping our decision-making processes (Ronningstam & Baskin-Sommers, 2013; Yang et al., 2018). Recognizing different fear triggers helps us understand their influence on our choices, leading to more informed decisions. Furthermore, this knowledge enhances communication by acknowledging and addressing various emotional triggers, facilitating more effective empathy and interaction. Additionally, this insight is valuable for health institutions in treating psychological disorders like phobias and anxiety through exposure therapy, helping individuals gradually confront and overcome their fears in a controlled environment.

5.0 CONCLUSIONS

This study's findings demonstrate that the nature of a fear-evoked stimulus, whether social or non-social, significantly influences the electrophysiological processes underlying fear responses. Specifically, our results show that social fear stimuli, such as images of human mutilation, elicit stronger brain responses than non-social fear stimuli, like images of wild animals. This implies that social context significantly influences the neural processing of fear.

These findings have important implications for the development of psychological interventions for fear-related disorders. Future research should investigate specific types of fear stimuli to enhance the effectiveness of therapies like exposure therapy, which aims to modify fear responses and promote emotional resilience. Furthermore, we need to conduct more research to comprehend the impact of gender on the emotional processing of fear, which could guide the development of more individualized treatment strategies for anxiety and phobias.

Overall, this study contributes to a deeper understanding of fear processing and highlights the need for continued research into how different stimuli and individual differences influence fear responses. Such insights will be invaluable for designing targeted interventions that address the complexities of fear and improve therapeutic outcomes.

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Author Contributions:
NY and HU conceptualized the framework and study design, and supervised the project. NSA, NY, and HU involved in the participant selection, data collection, and interpretation. NY and MAA contributed to the manuscript drafting, reviewing, and editing. All authors participated in writing the manuscript and approved the final version.

Conflicts of Interest:
The authors declared no conflict of interest.

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