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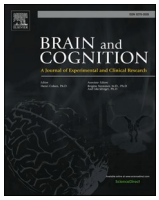

Event-Related potentials in visual attention to threatening and fearful Stimuli: A systematic review

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ABSTRACT

This systematic review aimed to synthesize event-related potential (ERP) findings relating to the processing of threat-related visual stimuli across different stimulus categories. We included peer-reviewed, empirical studies published between 2000 and 2024 which reported ERP data in response to visual, threat-related stimuli in adult human participants. We excluded studies using non-visual modalities or non-ERP outcomes. The systematic search of PubMed and Web of Science was conducted on 1 August 2024. Study selection was performed independently by two reviewers. We narratively synthesized ERP results by stimulus type and component. Twenty-four studies met the inclusion criteria, comprising samples of healthy participants. Most of the studies used facial expressions as stimuli, while others employed images of animals (e.g. snakes and spiders), modern threats (e.g. guns, knives), or environmental scenes. Early ERP components (e.g. P1, N1, and EPN) were modulated by biologically salient stimuli, which suggests rapid attentional capture. Later components (e.g. LPP) reflected sustained engagement and cognitive evaluation, with modulation patterns varying according to stimulus type, cognitive load and participant characteristics. The type of stimulus may affect ERP markers of threat processing. The findings emphasize the value of ERPs as precise indicators of emotional attention and suggest their potential as biomarkers in clinical research.

1. Introduction

Although fear is often considered as a negative emotion, the primary function of its underlying mechanisms is to detect threats in the environment and enable individuals to respond effectively to potentially dangerous situations (Bar-Haim et al., 2007; Öhman et al., 2001). Due to limited cognitive capacity, attention is naturally directed towards the most salient and relevant stimuli in one's surroundings (Connor et al., 2004). This selective focus helps to filter out irrelevant information, enabling individuals to prioritize and react to threats and dangers and enhancing their ability to protect themselves (Koster et al., 2004; LoBue & Rakison, 2013).

Attentional processes can be categorized as either bottom-up (exogenous) or top-down (endogenous) processes. Bottom-up attention is reflexive and is driven by the salience of a stimulus (Katsuki, 2013), such as the sudden appearance of a predator in one's environment. This type of attention operates rapidly and does not require conscious effort, enabling swift reactions to unexpected dangers. In contrast, top-down attention is more goal-directed and is shaped by expectations, past experiences and cognitive control mechanisms. It allows individuals to modulate their attention based on contextual information and personal relevance (Katsuki, 2013). Understanding these different attentional processes is crucial in life-threatening situations, as they might have an effect on how quickly and effectively individuals detect, interpret, and respond to danger.

To investigate attentional processes, researchers have developed a variety of experimental paradigms and computerized tasks that target specific components of attention. One widely used method is the dot-probe task, which assesses attentional bias towards threatening stimuli (MacLeod et al., 1986). Another method is the emotional Stroop task, which measures how task-irrelevant emotional threats interfere with cognitive performance (Stroop, 1935). Similarly, visual search tasks

Abbreviations: F, female; M, male; NA, not applicable., EPN: early posterior negativity, ERP: event-related potential, LPP: late positive potential, VEP: visual evoked potential, vMMN: visual mismatch negativity.

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examine attentional bias by investigating the impact of threatening targets or distractors on visual attention (Öhman et al., 2001). The emotional spatial cueing paradigm focuses on how individuals shift attention towards and disengage from threat-related cues (Fox et al., 2002; Posner et al., 1980), whereas tasks such as the visual oddball paradigm assess how attention is captured or suppressed in the presence of fear-related distractors. Together, these paradigms and tasks promote the understanding of how emotionally salient information competes for attentional resources and how individuals manage their focus in the context of perceived threat (Gupta et al., 2019).

To gain a deeper insight into the neural and physiological correlates of attentional processes in threat and fear perception, extensive research has been conducted that integrates experimental paradigms and computerized tasks with electrophysiological techniques. Electroencephalography (EEG) and event-related potentials (ERPs) provide valuable information on the temporal dynamics of threat processing. EEG measures brain activity via electrodes placed on the scalp. These electrical impulses, generated by neurons, can be analyzed to extract ERPs – the synchronized activation of neuron groups that is time-locked to an event (Kappenman & Luck, 2012).

Previous research has categorized ERPs into early (0–250 ms) and late (>250 ms) components following stimulus onset (Gupta et al., 2019). Early ERP components typically include C1, P1, N1, N170, P2, and N2, and are often associated with initial sensory and perceptual processing. In contrast, late components such as P3 and the late positive potential (LPP) are generally linked to higher-order cognitive functions, including attention and emotional evaluation. The labels "P" (positive) and "N" (negative) preceding ERP components refer to the polarity of the waveform, while the accompanying numbers or time windows indicate the approximate latency of the peak after stimulus onset. However, unlike most ERP components, the polarity of C1 can vary depending on stimulus location and other factors, making it an exception to the typical P/N labelling convention (Gupta et al., 2019).

A previous interpretive, though non-systematic, review by Gupta et al. examined the temporal dynamics of attention-related ERP responses to threat and fear stimuli, particularly in anxious individuals (Gupta et al., 2019). The study revealed that both healthy and clinically anxious participants (i.e., diagnosed with an DSM-5 anxiety disorder) exhibit modulation of early ERP components in response to threatening stimuli. However, healthy individuals demonstrate more consistent modulation of later components, reflecting the conscious evaluation of threat and the difficulty of disengaging attention during the later stages of processing. This approach allows us to provide a more nuanced synthesis of stimulus type, attentional dynamics, and individual differences across a wider set of contexts. A systematic review focused specifically on ERP correlates of attentional bias towards facial stimuli in the dot-probe task highlighted that methodological and sample-related variations may contribute to inconsistencies in findings (Torrence & Troup, 2017).

The type of (threat-related visual) stimulus used in a study may play an important role in shaping attentional and emotional responses. Emotional responses to visual stimuli could be affected by their semantic category, affective properties, ecological relevance, perceptual features, etc. (Coelho et al., 2023). Those with evolutionary relevance, such as threat from animals or angry faces, are often associated with stronger and more consistent subjective responses. Furthermore, recent findings demonstrate that variations in visual features or affective content, even within the same category (e.g. animals), can elicit distinct neural responses (Zsido et al., 2023). For instance, fear-relevant stimuli, such as the sight of blood or snakes, activate distinct visual and emotional processing pathways despite both being evolutionarily salient. These findings emphasize that attentional and affective systems are not uniformly responsive to all threats and suggest that stimulus-specific mechanisms may underpin variability in individual fear perception and threat detection. These differences highlight the importance of considering stimulus selection when interpreting neural data on emotion and attention.

Therefore, we conducted a systematic review to provide an up-to-date synthesis of research findings on the attentional processes involved in processing threat and fears, focusing particularly on ERP measures. Our aim was to clarify how attentional responses to threat- and fear-related visual stimuli are initiated and modulated at the attentional level, as reflected in specific ERP components.

2. Method

We prepared this systematic review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 checklist (Page et al., 2021). The completed checklist can be found as Supplementary Material. The review was not registered, and a review protocol was not prepared. The literature search was performed on August 1, 2024, using PubMed and Web of Science. The search strategy included the following combinations of keywords and filters: ((fear) OR (fearful) OR (threat) OR (threatening)) AND (visual attention) AND (ERP) Filters: English, Humans, Adult: 19 + years, from 2000 − 2024/7/31. We also filtered out any non-research type articles such as *meta*-analysis, reviews, technical reports, books, editorials, etc. To focus on the last two decades, during which ERP research on visual threat processing began to appear in sufficient numbers, we restricted the time frame to studies published from 2000 onward. These terms were applied to titles, abstracts, and full-text content to identify relevant studies. Table 1 shows all the inclusion and exclusion criteria we used.

There were no restrictions for experimental methodology or study design. This inclusive approach aimed to capture a comprehensive range of studies investigating the relationship between threat- and/or fear-related visual stimuli and attentional processes in the context of ERP markers.

The screening process focused on the relevance of each study to the core domains of attention, threat or fear processing, and electrophysiological measurements. This was done in two stages; first we shortlisted records that met the inclusion criteria based on their title and abstract, and then these were reviewed at full-text. In the second stage we applied the Newcastle–Ottawa Scale (Wells et al., 2000) to evaluate the methodological quality and potential risk of bias of the included studies. The Newcastle–Ottawa Scale assesses studies in three broad categories: (1) selection of participants, (2) comparability of groups and (3) ascertainment of outcomes. Two reviewers independently assessed each included study using this tool, resolving any discrepancies through discussion until consensus was reached. No automation tools were used in the process. Inter-rater reliability was $\kappa = 0.89$ indicating good

Table 1
The inclusion and exclusion criteria used to select studies.

Inclusion criteria	Exclusion criteria
Measured and reported ERP using EEG	Not reporting ERPs as an outcome measure or using MEG ERP
Published in peer-reviewed journals	Non-research articles (e.g., tutorials, lectures)
Classified as empirical research	Non-empirical papers (e.g., systematic reviews, *meta*-analyses, communication papers)
Utilized visual stimuli	Publications outside the 2000–2024 timeframe
Published between 2000 and 2024	Non-peer-reviewed sources (e.g., books, dissertations, pre-prints)
Written in English	Studies in languages other than English
Focused on adult human participants (18 years and older)	Research involving non-human subjects or participants under 18 years of age
Non-clinical sample	Neurological or psychiatric history
	Papers employing non-visual modalities (e.g., auditory, tactile) or combining visual stimuli with other types were excluded to maintain modality consistency

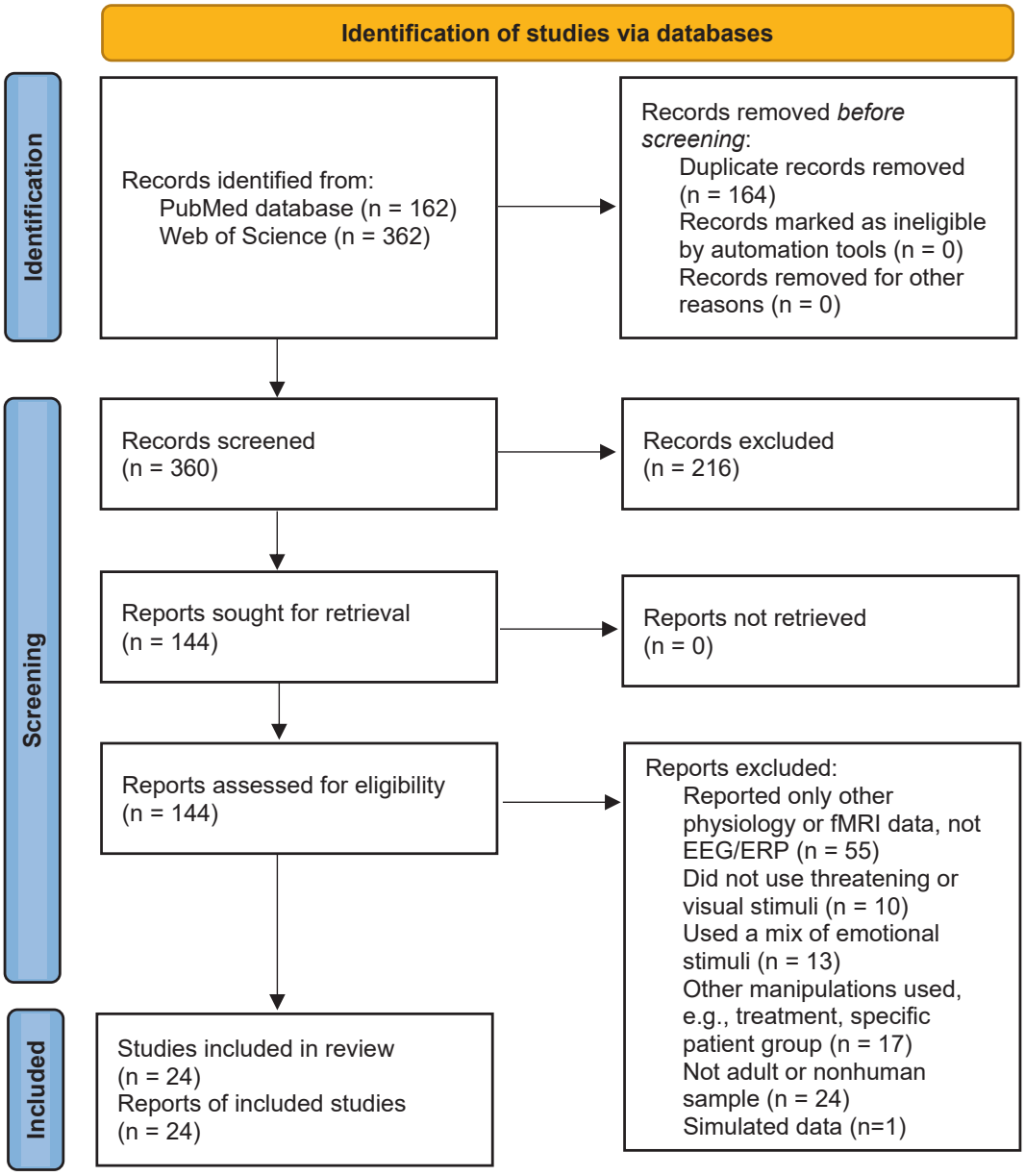

Fig. 1. PRISMA flow diagram of the selection and review process for review articles.

correspondence between the two screeners.

Due to the small number of studies included in each synthesis and the heterogeneity of paradigms, it was not feasible to conduct a formal quantitative assessment of reporting bias using methods such as funnel plots or regression analysis. Instead, we qualitatively assessed the potential for selective reporting by examining whether ERP components were analyzed and reported consistently across studies, and whether null results were explicitly described.

3. Results

The search yielded a total of 524 records published between 2000 and 2024. After careful consideration, 24 studies met the inclusion requirements (see Fig. 1 for a detailed overview of the selection steps). A summary of each article is presented in Table 2.

Thirteen studies investigated visual attention to threat using only facial stimuli, such as angry or fearful expressions. Seven studies focused exclusively on non-human animal stimuli (e.g., snakes and spiders). Four studies utilized a diverse set of threat-related visual stimuli, including environmental scenes (e.g., tornadoes, fires, tsunamis), facial expressions, weapons, and animals. See Fig. 2 for a quick visual overview of the core findings of our systematic review. It shows how many of the studies included found results for the particular ERP separately for each stimulus type.

The majority of the studies were conducted on young adults (aged between 20–30), we have no age data for two studies and another study included older adults (aged 60 +) besides the younger group. Although all studies with the exception of two included both males and females, overall, the majority of participants were female. We sought to only include studies conducted on a healthy sample, defined as having had no neurological or psychiatric diagnosis history. This did not preclude the inclusion of studies reporting individual differences (e.g., high/low anxiety or depression, fearful participants) besides the main results. All studies included healthy participants, with the exception of Experiment 2 of one study (Arad et al., 2019) that included participants with social anxiety disorder. We did not include this experiment in the review.

Table 2
Summary of included articles.

Author	Year	N	Age[a]	Sex	Condition	Individual differences	Stimuli		Task(s)	Main Finding(s)	DOI
Abado et al.	2024	30	23	F = 24, M = 6	Healthy	NA	Animals	spiders	Visual detection task	EPN and LPP amplitudes were larger for spider targets compared to bird targets.	https://doi.org/10.1111/psyp.14546
Arad et al.	2019	30	27	Study 1 = F = 18	Healthy	NA	Facial expression	angry	Dot-probe task	vMMN amplitude was greater in the neutral group than in the angry group.	https://doi.org/10.1002/da.22858
Balconi & Pozzoli	2008	21	23	F = 10, M = 11	Healthy	NA	Facial expression	fearful	Stimulus elaboration task	Emotional faces elicited a negative peak at approximately 230 ms (N230). However, emotional faces were considered as one category.	https://doi.org/10.1080/00207450601047119
Bar-Haim Y et al.	2005	24	23	F = 19, M = 5	Healthy	Anxiety level	Facial expression	fearful	Attention shifting task	P1 amplitude was lower in response to fearful stimuli than others, regardless of group, while faster P1 latency was observed in the high-anxious group compared to the low-anxious group, regardless of stimuli. N1 amplitude was greater in response to fearful stimuli regardless of group, while faster N1 latency was observed in the high-anxious group compared to the low-anxious group, regardless of stimuli. P2 amplitude was greater in response to only angry faces in the high-anxious group compared to the low-anxious group, while faster P2 latency was observed in the high-anxious group compared to the low-anxious group, regardless of stimuli.	https://doi.org/10.1016/j.bandc.2005.03.005
Brown et al.	2010	32	NA	NA	Healthy	NA	Mixed	spiders, snakes, knives, syringes	Dot-probe	Threats lead to increased P1 amplitude. The effect is stronger for modern (knives, syringes) compared to evolutionarily relevant (spiders, snakes) threats.	https://doi.org/10.1016/j.bandc.2010.08.008
Carretié et al.	2005	31	21	F = 23, M = 8	Healthy	Spider fearfulness	Animals	spiders	Visual detection task	P150 and N500 were greater for spiders than for non-spiders. Ventromedial prefrontal areas previously reported as responding rapidly to danger-related (conscious) stimuli were activated by unconsciously perceived spiders more markedly than by nonnegative unconscious stimuli. Around 500 ms after stimulus onset, activation of the posterior cingulate and visual association cortices increased in this same direction.	https://doi.org/10.1016/j.neuroimage.2004.09.009
Cavanagh & Geisler	2006	36	NA	F = 24, M = 12	Healthy	Depression level	Facial expression	fearful	Visual oddball task	Both happy and fearful stimuli showed significantly reduced P3 amplitudes and P3 latencies	https://doi.org/10.1016/j.ijpsyhco.2005.04.005
Flykt & Caldara	2007	18	22	F = 14, M = 4	Healthy	Spider fearfulness	Animals	spiders	Visual oddball task	Larger LPP amplitudes (between 500 ms and 700 ms from stimulus	https://doi.org/10.1080/02699930500381405

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Table 2 (*continued*)

Author	Year	N	Age[a]	Sex	Condition	Individual differences	Stimuli		Task(s)	Main Finding(s)	DOI
Abado et al.	2024	30	23	F = 24, M = 6	Healthy	NA	Animals	spiders	Visual detection task	EPN and LPP amplitudes were larger for spider targets compared to bird targets.	https://doi.org/10.1111/psyp.14546
										onset) for spiders compared to fear-irrelevant targets.	
Grassini et al.	2019	20	23	F = 16, M = 4	Healthy	NA	Animals	snakes, ropes	Rapid serial visual presentation	Enhanced P1, N1, and EPN for threats.	https://doi.org/10.1037/emo0000434
Holmes et al.	2003	18	24	F = 11, M = 7	Healthy	NA	Facial expression	fearful	Visuospatial cueing task	When faces were attended, a greater frontal positivity in response to arrays containing fearful faces was obtained, starting about 100 ms after stimulus onset (N1), so N1 reduced in amplitude. N170 component was unaffected by emotional facial expression, but N170 amplitudes were enhanced when faces were attended.	https://doi.org/10.1016/S0926-6410(02)00268–9
Kappenman et al.	2014	96	20	F = 50, M = 46	Healthy	NA	Mixed	animals attacking, assault, guns	Dot-probe	N2pc revealed a significant initial shift of covert attention in the direction of the threatening image.	https://doi.org/10.3389/fpsyg.2014.01368
Langeslag & van Strien	2018	25	21	F = 12, M = 13	Healthy	NA	Mixed	snakes, angry faces	Rapid serial visual presentation	Enhanced EPN for both angry faces and snakes; similar between 150–225 ms, but larger for snakes between 225–300 ms.	https://doi.org/10.1016/j.brainres.2017.10.031
Mathieu et al.	2014	28	Young: 24 Old: 62	F = 14, M = 14	Healthy	NA	Mixed	threatening animals (spider, shark, snake, etc.) and environments (tornado, fire, tsunami, etc.), aggressive people (carrying weapons, angry expressions, etc)	Emotional categorization task	LPP amplitude for negative stimuli was reduced in older adults compared to younger adults	https://doi.org/10.1371/journal.pone.0099523
Pourtois et al.	2004	20	Experimental group = 22; control group = 23	F = 14, M = 6	Healthy	NA	Facial expression	fearful	Spatial orienting task	The lateral occipital P1 component was selectively increased when a bar replaced a fearful face compared to when the same bar replaced a neutral face. This effect was not found with upright happy faces or inverted fearful faces. In addition, VEPs time-locked to the face-pair onset revealed a C1 component that was greater for fearful than happy faces.	https://doi.org/10.1093/cercor/bhh023
Pourtois et al.	2005	12	22	F = 9, M = 3	Healthy	NA	Facial expression	fearful	Covert orienting task	Stronger P1 response on valid relative to invalid trials following fearful faces.	https://doi.org/10.1016/j.neuroimage.2005.01.015
Qui et al.	2022	22	23	F = 16, M = 6	Healthy	NA	Facial expression	fearful	Dot-probe	Fearful expressions enhanced N2 and P3 only in the supraliminal viewing condition.	https://doi.org/10.3390/brainsci12070823
Righart & de Gelder	2006	12	21	F = 10, M = 2	Healthy	NA	Facial expression	fearful	Orientation-decision task	The presence of a face in a fearful context enhances the N170 amplitude over a face in neutral contexts, an effect that is strongest for fearful faces on left occipito-	https://doi.org/10.1093/cercor/bhj066

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Table 2 (*continued*)

Author	Year	N	Age[a]	Sex	Condition	Individual differences	Stimuli		Task(s)	Main Finding(s)	DOI
Abado et al.	2024	30	23	F = 24, M = 6	Healthy	NA	Animals	spiders	Visual detection task	EPN and LPP amplitudes were larger for spider targets compared to bird targets.	https://doi.org/10.1111/psyp.14546
										temporal sites. This N170 effect, and the corresponding topographic distribution, was not found for contexts-only, indicating that the increased N170 amplitude results from the combination of face and fearful context. There was a main effect of facial expression in that latencies were prolonged for fearful as compared with neutral faces.	
Soares et al.	2017	24	19	F = 23, M = 1	Healthy	NA	Animals	snakes and spiders	Letter discrimination task	P1 showed greater amplitude to snakes, which was followed by an enhanced LPP showing enhanced amplitudes to spiders.	https://doi.org/10.1016/j.neuropsychologia.2017.03.007
Suway et al.	2013	34	21	F = 34	Healthy	NA	Facial expression	angry	Dot-probe task	Compared to controls, those in the training group showed greater depression vulnerability to a post-training stressor and increased P2 amplitude, an ERP component associated with attention toward threat, during the dot-probe task.	https://doi.org/10.1016/j.jbtep.2012.11.006
Van Dillen & Derks	2012	15	20	F = 15	Healthy	NA	Facial expression	angry	Gender-naming task	Under low (but not high) cognitive load, N2 amplitudes were smaller to angry compared to happy faces. Moreover, high load reduced LPP amplitude and eliminated the enhanced LPP to angry compared to happy faces that were present under low load.	https://doi.org/10.1037/a0028624
van Strien et al.	2015	24	21	F = 13, M = 11	Healthy	NA	Animals	snakes, spiders	Rapid serial visual presentation	Enhanced EPN (225–300 ms after onset) to snakes and spiders compared to neutral stimuli. Snakes elicited greater amplitude than spiders.	https://doi.org/10.1111/psyp.12564
Weymar et al.	2012	50	23	F = 41, M = 9	Healthy	Spider fearfulness	Animals	spiders	Visual oddball task	Spider stimuli evoked significantly larger N1 and N2pc amplitudes than butterflies	https://doi.org/10.1111/psyp.12008
Wijers & Banis	2012	16	22	F = 11, M = 5	Healthy	NA	Facial expression	fearful	Sustained attention task	The P1 amplitude was larger for fearful faces than for neutral faces. P1 was significant only over the right hemisphere.	https://doi.org/10.1016/j.clinph.2011.07.040
Zhu & Luo	2012	16	22	F = 9, M = 7	Healthy	NA	Facial expression	fearful	Stroop task	There was a modulation of C1 in response to fearful faces versus happy faces. The differentiation between detection of fearful and happy faces emerged at 60–90 ms after the stimulus onset at the posterior electrode sites, and this early differentiation occurred regardless of whether the subject had viewed a congruent or incongruent	https://doi.org/10.1016/j.neulet.2012.08.011

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Table 2 (*continued*)

Author	Year	N	Age[a]	Sex	Condition	Individual differences	Stimuli		Task(s)	Main Finding(s)	DOI
Abado et al.	2024	30	23	F = 24, M = 6	Healthy	NA	Animals	spiders	Visual detection task	EPN and LPP amplitudes were larger for spider targets compared to bird targets.	https://doi.org/10.1111/psyp.14546
										trial (i.e., a happy face with a fear label or vice versa).	

[a] Rounded to the closest integer.

Overall, most studies were judged to be of moderate risk of bias, primarily due to small sample sizes and limited reporting of participant selection procedures. Several studies lacked detailed descriptions of randomization or blinding (if any) of stimulus presentation, and few reported preregistration or power analyses. However, the methods used to acquire and analyze ERP data were generally well documented, and the outcome measures were clearly reported across studies. Selective reporting of ERP components cannot be ruled out across studies. Several studies only reported significant ERP findings, while null results were often omitted or described inadequately. None of the included studies were preregistered, and few provided open data or analysis scripts. This pattern suggests that reporting bias may have influenced the evidence base.

3.1. Early ERP components.

Modulation of the P1 component was the most consistently reported early effect. While Bar-Haim et al. (2005) found a general reduction in P1 amplitude to fearful faces regardless of anxiety status, other studies reported enhanced P1 responses to fearful faces under valid cueing conditions (Pourtois et al., 2005) and stronger right-hemisphere (Wijers & Banis, 2012). Interestingly, Pourtois et al. (2004) demonstrated that emotional modulation of P1 extended to non-face stimuli that had previously been associated with fear, suggesting the modulation is specific to the emotional salience of upright fearful faces and highlighting the impact of associative learning. Four studies (Brown et al., 2010; Grassini et al., 2019; Soares et al., 2017; Weymar et al., 2012) added evolutionary relevance showing that P1 amplitude was also greater for animal threats. Furthermore (Soares et al., 2017; Weymar et al., 2012) noted that snakes elicited greater P1 responses than spiders, birds or visually similar objects (ropes), suggesting a biologically prepared attentional bias for ancestral threats. Interesting, Brown and colleagues (2010) found that the amplitude was greater for modern threats compared to evolutionary relevant ones. The P150 component, localized to ventromedial prefrontal regions, also showed enhanced responses to unconsciously perceived spiders, supporting the idea that even subliminal threat cues can engage affective processing regions (Abado et al., 2024; Carretié et al., 2005).

ERP components in the 100–300 ms window reflect more differentiated perceptual and attentional processing. Two studies using facial stimuli (Holmes et al., 2003; Bar-Haim et al., 2005), and one using animal-related stimuli (Grassini et al., 2019) found that threatening stimuli enhanced early frontal positivity and N1 negativity, suggesting facilitated attentional engagement with threat. Furthermore, faster N1 latency in high-anxiety individuals suggests a heightened sensitivity to emotionally salient stimuli. These effects were localized to extrastriate areas, consistent with rapid visual discrimination mechanisms (Wijers & Banis, 2012). The N170, traditionally associated with the structural encoding of faces, showed mixed sensitivity to emotional content. While Holmes et al. (2003) found no modulation by emotion, Righart and de Gelder (2006) observed greater N170 amplitudes to fearful faces, especially over the left occipito-temporal region. This suggests that emotional content may interact with structural face processing under specific attentional or contextual conditions.

Bar-Haim and colleagues (Bar-Haim et al., 2005) reported that angry faces evoked larger P2 amplitudes in high-anxiety individuals, whereas P2 latency was generally faster in this group. Suway et al. (2013) extended these findings by showing that increased P2 amplitude predicted vulnerability to post-training stress in a depression-related context, indicating P2 as a marker of emotional reactivity or attentional capture. Regarding N2 and N230, emotion effects appeared conditional. Balconi and Pozzoli (2008) found a clear N230 response to emotional faces, while Van Dillen and Derks (2012) reported that angry faces reduced N2 amplitude only under low cognitive load, suggesting cognitive resources mediate the processing of emotional discrepancies. Qiu and colleagues (Qiu et al., 2022) found that fearful facial

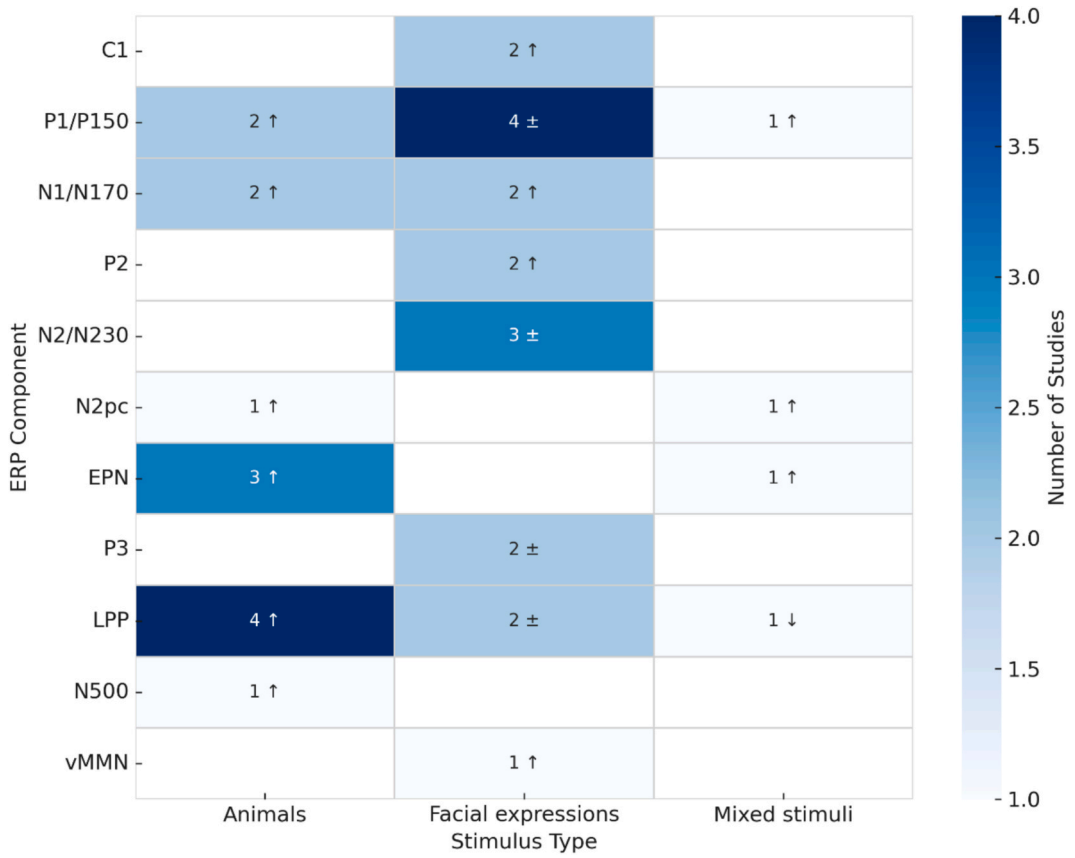

Fig. 2. Summary of event-related potential (ERP) components modulated by different categories of threat-related visual stimuli in the reviewed studies. The heatmap shows the number of studies reporting modulation of each ERP component (rows) by each stimulus type (columns). The direction of modulation is indicated as ↑(enhanced), ↓(reduced), or ± (mixed/context-dependent).

expressions only elicit enhanced N2 when presented below the supraliminal threshold. Two studies (Kappenman et al., 2014; Weymar et al., 2012) reported larger N2pc amplitudes for threatening compared to neutral targets.

Three studies (Abado et al., 2024; Grassini et al., 2019; van Strien et al., 2015) also noted greater EPN (early posterior negativity) amplitudes for threatening animals (snakes and spiders) compared to neutral ones. An early occipito-temporal component around 200–300 ms post stimulus onset that has been argued to reflect enhanced attention toward evolutionary relevant, emotionally charged stimuli. Langeslag and van Strien (2018) reported greater EPN for both snakes and angry faces.

3.2. *Late ERP components.*

The P3 component, which indexes higher-order cognitive evaluation and categorization, was found to be sensitive to emotional valence and intensity. Cavanagh and Geisler (2006) demonstrated that participants scoring high on a depression scale had reduced P3 amplitudes and delayed latencies to fearful (as well as happy) faces, suggesting deficits in evaluating positive emotional content. These alterations in timing and amplitude may reflect blunted or inefficient emotional evaluation systems in mood disorders. Qiu and colleagues (2022) found that fearful facial expressions only elicit enhanced P3 when presented below the supraliminal threshold.

The LPP component, known to reflect sustained attention and affective elaboration, was modulated by both cognitive load and age. Van Dillen and Derks (2012) showed that high cognitive load eliminated the typical LPP enhancement for angry faces, emphasizing the importance of attentional resources in later-stage emotional processing. Mathieu et al. (2014) added a developmental dimension by showing that older adults exhibited reduced LPP responses to negative stimuli, regardless of arousal, possibly reflecting age-related shifts in emotional regulation. Complementarily, Soares and colleagues (2017) found that LPP was enhanced for snakes – and two other studies (Abado et al., 2024; Flykt & Caldara, 2007) for spiders – at longer durations, underlining the role of evolutionary salience and stimulus persistence in prolonged emotional engagement.

At even later stages, N500 amplitudes were greater for spider stimuli and were accompanied by increased activation in the posterior cingulate and visual association cortices (Abado et al., 2024; Carretié et al., 2005). This suggests that biologically relevant threats continue to engage processing systems well beyond initial perceptual stages, potentially supporting the consolidation of threat memory or preparation for defensive responses. Finally, Arad et al. (2019) reported that vMMN amplitudes were higher in individuals exposed to neutral versus angry stimuli, and that these amplitudes predicted improvements following attention bias modification therapy, accounting for meaningful variance in both clinician-rated and self-reported symptoms. This positions vMMN as a promising biomarker for treatment responsiveness, particularly in anxiety-related disorders.

4. Discussions

This systematic review synthesized the findings from 24 studies that investigated the neural correlates of visual attention to threat using ERPs. While most of these studies focused on facial emotional expressions, specifically fear and anger, others expanded the scope to include evolutionarily relevant stimuli such as snakes and spiders, as well as complex environmental threats. Together, these studies provide a more nuanced understanding of how threat-related stimuli modulate the early

and late stages of visual processing. These effects could also be associated with individual differences such as anxiety, depression, age, or cognitive load.

The earliest ERP components, such as C1 and P1, reflect initial sensory encoding and are typically not modulated by top-down factors. However, results from studies identified by this review found that emotional salience can exert influence even at these early stages. Pourtois et al. (2004) and Zhu & Luo (2012) showed that fearful faces can enhance C1 amplitude, with effects observable within 60–90 ms post-stimulus. Such findings challenge the traditional view of C1 as immune to emotional influences and support the hypothesis of rapid subcortical pathways contributing to early threat detection.

Beyond summarizing ERP modulations across stimulus types, this review clarifies how the temporal profile of attentional processing may be shaped by the emotional content and ecological and perceptual characteristics of stimuli. Our results point to the possibility that biologically salient stimuli (e.g. snakes and spiders) may engage early sensory ERP components (e.g. P1 and EPN) more reliably than socially constructed or abstract threats. This supports theories of evolutionarily prepared fear systems (LeDoux et al., 1990; Öhman et al., 2001; Rachman, 1977; Soares et al., 2017). This observation corroborates, yet also builds upon, the findings of previous studies such as those in a previous review (Gupta et al., 2019), which primarily focused on attentional bias mechanisms and early/late ERP distinctions without systematically differentiating by stimulus type. To the best of our knowledge, no systematic review has examined ERP components associated with attentional processes in response to threat- and fear-related visual stimuli in various contexts, such as medical, environmental, non-human animal, and facial imagery. Prior reviews examined one paradigm or population (e.g. Torrence & Troup, 2017) or focused primarily on early versus late ERP components (e.g., Gupta el al, 2019). Our systematic review covers a diverse range of stimuli, providing a more comprehensive framework for understanding how different categories of threat activate distinct neurocognitive mechanisms. Nevertheless it must be noted that we only found a handful of studies directly comparing stimuli types and we mostly base this argument on comparison of studies that may use different methodology or samples. By incorporating evidence from both facial and non-facial stimuli, as well as individual differences, we suggest that the capture of attention by threat may not be fully uniform, but could potentially vary across ERP stages, stimulus categories and individual differences.

Importantly, our review builds on previous findings by systematically comparing how different categories of threat-related visual stimuli affect ERP components. While most studies have focused on facial expressions, particularly fearful and angry faces, our synthesis also incorporates research using non-human animals (e.g. snakes and spiders), objects (e.g. knives, guns) and a mix of threatening events (e.g. disasters, assaults). Although the number of the studies are scare, a broader range of stimuli raises the possibility that evolutionarily relevant threats, such as snakes and spiders, could elicit stronger early components, such as the P1 and LPP, even with brief exposure. Although mixed stimuli (often including evolutionarily relevant categories such as animals and environmental threats) were used less frequently, they still demonstrated modulation of late components, such as the LPP, particularly in relation to age-related differences in emotional processing. On the one hand, this may suggest a biologically prepared attentional bias towards them (Bar-Haim et al., 2007). Similarly, spiders evoked enhanced N500 amplitudes and activation in the posterior cingulate cortex, indicating prolonged engagement with fear-relevant stimuli. On the other hand, these interpretations should be treated with caution. Differences attributed to evolutionary salience could also be due to other factors, such as variations in arousal, valence, or the low-level psychophysical properties of the images (Coelho et al., 2023; Grassini et al., 2019; Zsido, 2024). For example, snakes and spiders may differ in terms of not only ecological relevance, but also visual complexity and typical affective ratings, which could partly explain the observed ERP differences. Better-controlled stimulus sets are needed in future studies to disentangle evolutionary relevance from these potential confounds. Taken together, these findings are in line with previous studies noting that stimulus type may influence the temporal dynamics of threat processing (Coelho et al., 2023) and that different categories of threat could engage partially distinct neural mechanisms (Zsido et al., 2023), even within similar ERP time windows.

There are some limitations to this review that should be acknowledged. Firstly, despite repeating the systematic search using both PubMed and Web of Science, the number of eligible studies remains limited. In particular, conclusions regarding specific stimulus categories and ERP components are often based on a small number of studies, with some findings reported in only one study. Therefore, the nuanced differences described should be interpreted with caution. Secondly, most comparisons across stimulus categories are indirect because only one study contrasted multiple categories within the same experimental design. Direct within-subject comparisons are needed to provide stronger evidence of differences in neural processing across stimulus types. Thirdly, although we identified additional relevant studies through Web of Science, our search did not include other databases (e.g. APA PsycInfo) or grey literature, which may have limited the comprehensiveness of our results. Fourthly, the inclusion of "visual attention" as a keyword was designed to capture experimental paradigms directly relevant to attentional processes; however, we recognize that this choice may have limited the scope by excluding some studies that employed related constructs (e.g., "attentional bias," "perceptual processing") without explicitly using the term "visual attention." Similarly, we excluded reviews and *meta*-analyses from the final synthesis but note that we screened their reference lists to ensure no eligible studies were missed. Finally, our risk of bias and reporting bias assessments revealed concerns relating to small sample sizes, limited transparency when reporting null results and a lack of preregistration across the literature. These methodological constraints further limit the reliability and generalizability of existing findings. Taken together, these limitations highlight the need for more systematic, transparent and comparative research on ERP correlates of threat-related attention.

This review provides compelling evidence for the enhanced processing of threat-related stimuli at multiple stages of visual attention. Our findings highlight the importance of considering stimulus selection as a theoretical variable in future studies, rather than just a design choice. For instance, within-subject comparisons of various threat categories (e.g. snakes, spiders, and angry faces) would yield more robust evidence of category-specific neural responses than indirect comparisons across individual studies. Similarly, systematically manipulating visual dimensions such as spatial frequency, contrast or image complexity would clarify whether observed ERP differences reflect emotional significance or basic perceptual features. Integrating naturalistic threat stimuli with standardized image sets could also help to balance ecological validity with experimental control. These approaches would advance the field by linking stimulus selection directly to theoretical predictions about attentional and emotional processing. ERP components such as the LPP and N500 may serve as markers of sustained engagement or evaluative processing for specific threat types. This makes them particularly useful in clinical research on anxiety, phobias, and treatment response. ERPs may also have potential applications as biomarkers in clinical research. Components such as the P1, EPN, and LPP are sensitive to threat-related stimuli and could serve as candidate indices of attentional biases that play a role in the onset and maintenance of anxiety disorders. As well as characterizing clinical populations, such measures could be useful in evaluating the efficacy of interventions or predicting treatment outcomes. However, we emphasize that the current literature is limited in scale and consistency, and replication in larger, preregistered studies will be essential before these can be used in a clinical setting.

The findings highlight the sensitivity of various ERP components to threat, from early sensory processing to later cognitive evaluation. These

results contribute to our understanding of the neural mechanisms underlying fear and anxiety and have implications for the development of targeted interventions for anxiety disorders. In order to fully understand how different types of threat stimuli engage attentional and emotional processes, more studies employing a wider range of ecologically valid stimuli are needed. Methodological consistency, such as standardized stimulus sets and harmonized ERP time windows, would further enhance comparability across studies. It is also important to consider that ERP components can vary in their scalp topographies across studies, and such variability may influence interpretation of the underlying neural processes. Although here we focused on studies where threatening stimuli were presented as task-relevant ones, another review should also consider ERPs (e.g., N2pc) associated with threats presented as distractors (Burra et al., 2016; Wirth & Wentura, 2023). This would enable future research to more accurately characterize the specificity, generalizability, and clinical relevance of ERP markers in fear and threat processing.

CRediT authorship contribution statement

Atakan M. Akil: Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Greti Gaspar:** Writing – review & editing, Writing – original draft, Resources, Investigation, Data curation. **Daniela C. Gonçalves-Bradley:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology. **Andras N. Zsido:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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