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Review

Neuronal underpinnings of the attentional bias toward threat in the anxiety spectrum: Meta-analytical data on P3 and LPP event-related potentials

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ABSTRACT

Background: This systematic review analyzes brain responses at later stages of neuronal processing (P3 at 300–500 ms, and LPP at 300–700 ms). Both P3 and LPP are implicated in attentional threat bias in disorders grouped into fear and distress dimensions of the anxiety spectrum described by the Hierarchical Taxonomy Model of Psychopathology (HiTOP), but there are no consistent findings so far.
Method: Meta-analyses with between- (32 studies, $n = 1631$) and within-groups design (31 studies, $n = 1699$) were performed for assessing P3 and LPP modulation in negative, positive, and neutral stimuli, while also considering differences between controls and anxious individuals. Relevant moderators (e.g., age, sex, task) were controlled for and negative stimuli were further decomposed in terms of category (Relevant, Fear/Threat, or Unpleasant).
Results: Increased P3 and LPP amplitudes were found for negative and positive stimuli, when compared to neutral stimuli (within-subjects analysis), confirming that both components are elicited by emotionally arousing information. Within-effects for negative and positive stimuli were higher for the anxious groups. Nonetheless, between-groups analyses showed that attentional threat bias occurs only in anxious groups when negative, personally relevant-threat information is presented. The HiTOP fear dimension moderated the findings.
Limitations: Potential missed studies; ERPs time windows' heterogeneity; adult sample only; the uneven number of computed effects; categorical analyses.
Conclusion: Attentional bias toward disorder-congruent threatening cues can be a transdiagnostic mechanism of HiTOP fear disorders, clustered within the anxiety spectrum.

1. Introduction

Anxiety is a natural emotional reaction to potentially dangerous situations (Cannon, 1915, Bateson et al., 2011). It has its roots in human evolution and can be considered adaptative in many scenarios. It is part of the threat and self-protection systems and allows living beings to pick up appropriate behavioral responses, increasing their chances of survival. However, when characterized by persisting or severe distress, anxiety-like symptoms will interfere with normal functioning (Beesdo et al., 2009). Anxiety disorders represent the extreme endpoint of the severity continuum of fear and distress systems and are characterized by heightened behavioral and cognitive responses to threat-relevant stimuli, as well as elevated amygdalae and physiological responses to such stimuli (Craske et al., 2009; Lang et al., 2016; Stein, 2014). These latter aspects integrate a core mechanism of anxiety - the so-called attentional bias toward threat.

Attentional bias can be understood as the propensity to prioritize the processing of specific stimuli over others (Azriel & Bar-Haim, 2020). In our daily lives, our senses receive countless stimuli at the same time, but the human mind is not capable of processing them all equally. Attention reduces processing load by acting as a filter that blocks irrelevant inputs and prioritizes a set of orienting responses towards a limited number of sensory information (Broadbent, 1957; Duncan, 1980; Treisman, 1969; Azriel & Bar-Haim, 2020). So, attention-like bias can be considered a cognitive mechanism that allows individuals to adaptively process environmental stimuli, contributing to their optimal functioning. More specifically, attentional biases towards potential threats are a primary and involuntary mechanism that played an extremely important role in

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the survival of the human species throughout evolution. It protects individuals from real hazards by allowing them to scan their surroundings and be hypervigilant for danger cues. Attentional bias toward threat reflects, therefore, a set of orienting responses that prioritize the processing of salient threats over neutral stimuli (e.g., Azriel & Bar-Haim, 2020; Bar-Haim et al., 2007; Brotman et al., 2007; Dennis-Tiwary et al., 2019; Fox et al., 2001, 2002; Hakamata et al., 2010; Mansell et al., 2008; Mathews & Mackintosh, 1998; Mathews & MacLeod, 1985, 2002, 2005).

Some individuals are highly sensitive to threat-relevant stimuli, even if they are essentially ambiguous and pose little or no danger. From the perspective of Attention Control Theory (Eysenck et al., 2007), anxiety may impair the balance between the two main systems of attentional control, increasing the influence of the stimulus-driven attentional system (i.e., automatic orientation towards salient stimuli) over the goal-directed attentional system (i.e., voluntary attention towards a motivating goal) (e.g., Blair et al., 2007; Corbetta & Shulman, 2002; Coombes et al., 2009). Disrupted attentional mechanisms may also influence other cognitive processes in anxiety. Threat-biased mental schemas of anxious individuals possibly influence how they organize and categorize their surrounding environment as overly hostile (e.g., Azriel & Bar-Haim, 2020; Bar-Haim et al., 2007; Beck & Clark, 1997; Eysenck & Calvo, 1992; Mogg & Bradley, 1998).

It is still unclear whether attentional bias acts as a risk factor for the etiology and maintenance of anxiety symptoms (Abend et al., 2018; Bar-Haim et al., 2007) or if anxiety shapes the way individuals see the world, influencing their cognitive bias (e.g., Abend et al., 2018; Bar-Haim, 2010; MacLeod et al., 2002). There is a growing consensus that a bidirectional relationship probably exists – a hypothesis that has received support in the literature (see Van Bockstaele et al., 2014 for a review), with longitudinal and genetic evidence supporting the role of attentional bias in the onset of anxiety (Bardeen & Daniel, 2018; Beevers et al., 2009; Creswell & O'Connor, 2011; Eley et al., 2007; Fox et al., 2009; Gibb et al., 2016; Pergamin-Hight et al., 2012), and vice-versa (Blossom et al., 2013; Domschke & Maron, 2013; Eley et al., 2007; Hadwin et al., 2006; Lester et al., 2009). In this regard, a recent study illustrates the complexity of the interactions described above: not only do anxiety-induced states increase attentional bias toward negative stimuli, but the modification of attentional bias can also influence anxiety under stressful conditions (Liu et al., 2019). Thus, it is likely that a feedback loop exists between both constructs, that maintains and possibly amplifies the threat-related attentional bias itself as well as the intensity of anxiety symptoms (Azriel & Bar-Haim, 2020; Creswell & O'Connor, 2011; Eldar et al., 2008; Eysenck, 1997; Mathews & MacLeod, 2002).

Alterations in attentional bias toward threat have been observed across disorders that can be clustered in the so-called anxiety spectrum - Generalized Anxiety Disorder, Separation Anxiety Disorder, Social Anxiety Disorder, Specific Phobia, Selective Mutism, Panic Disorder, Agoraphobia, Posttraumatic Stress Disorder, and Obsessive-Compulsive Disorder (e.g., DSM-5; American Psychiatric Association, 2013; Bar-Haim et al., 2007; Cisler et al., 2007; Frewen et al., 2012; Gardner et al., 1994; Mogg et al., 2004; Rao et al., 2010; Spielberger & Vagg, 1995; Staugaard, 2010) - as well as in subclinical samples(Dennis-Tiwary et al., 2019; Fu & Perez-Edgar, 2019; Rogers et al., 2020). As such, attentional bias toward threat is a promising transdiagnostic mechanism, cross-cutting the boundaries of anxiety disorders that were initially considered to be independent (Garland & Howard, 2014; Mansell et al., 2008; Rogers et al., 2020). Recent approaches to psychopathology, such as the Hierarchical Taxonomy of Psychopathology (HiTOP; Kotov et al., 2017) convey such transdiagnostic viewpoints and encourage researchers to search for shared mechanisms across the psychopathological spectrum.

HiTOP offers a compelling empirical framework to explore the hierarchical organization and the full complexity of psychopathology structures - starting from the most basic units (e.g., symptoms) and ending at higher levels of generality (i.e., high-order latent factors). To reduce heterogeneity, HiTOP defines narrow symptoms and traits which are then grouped into psychopathology spectra, reflecting the covariance between disorders (Forbes et al., 2021; Kotov et al., 2017). According to this model, two latent subfactors of the broad dimension of internalizing spectrum – fear and distress – can explain patterns of covariation between anxiety-related disorders. The Fear subfactor clusters social phobia, agoraphobia, specific phobia, and obsessive-compulsive disorder. The Distress subfactor includes generalized anxiety disorder and post-traumatic stress disorder. Both factors are expected to account for comorbidities across the internalizing spectrum, unraveling transdiagnostic mechanisms of psychopathology such as attentional bias.

To date, attentional bias in anxiety-related disorders has been the subject of systematic reviews and meta-analyses but mostly at the behavioral level. Overall, data reveals that vulnerability toward anxiety is characterized by attentional hypervigilance toward threats (Armstrong & Olatunji, 2012; Dudeney et al., 2015; Macleod et al., 2019). Anxious individuals seem to show difficulties in withdrawing attention from negative/threatful stimuli (Rogers et al., 2020), regardless of the experimental paradigm or conditions (Bar-Haim et al., 2007). A recent meta-analysis by Clauss and colleagues (2022) found a relationship between anxiety and fear-related symptoms and both reflexive orienting and maintenance of attention to threat, suggesting that individuals with anxiety symptoms seem to display an attentional bias toward threat at both stages of visual processing.

Overall, research reveals that attentional bias in anxiety is specific to threatening stimuli. This directly contradicts the emotionality hypothesis, which states that emotional stimuli in general (either positive or negative) would attract more attention compared to non-arousing neutral stimuli in anxious individuals (Martin et al., 1991; Sass et al., 2010). Remarkably, a meta-analysis from Pergamin-Hight and colleagues (2015) revealed that attentional bias toward threat in anxiety-related disorders seems to be mostly observed during the presentation of disorder-congruent threatening stimuli, meaning that attentional resources are particularly directed to relevant threat information triggering individuals' fears (e.g., spider images and specific spider phobia, death images and post-stress traumatic disorder in war veterans). This relates to the *content specificity* concept (Mathews & Macleod, 1994; Yiend et al., 2018; Trotta et al., 2021), which states that a bias is stronger if the information being processed is highly arousing and relevant to the individual. Moreover, it also supports cognitive theories stressing the role of schema-driven threat processing in anxiety. These complex cognitive structures influence how individuals process the environment, activating related psychobiological systems (Beck & Haigh, 2014). In anxiety, cognitive schemas likely provide selective (threat) information to basic functioning systems, which compromises adaptive functioning (Clark & Beck, 2011).

Despite all these interesting theoretical considerations and findings, studies to date mostly rely on behavioral indicators (e.g., reaction times), which are only able to capture the end-stage output of attention processes and do not offer a direct pathway to look at the way the human brain allocates attentional resources to process threat (Fu & Perez-Edgar, 2019).

Current research places a great interest in Electroencephalography (EEG) and Event-Related Potentials (ERPs) to study the attentional bias toward threat in anxiety. ERPs can accurately track the time course of neuronal responses to different stimuli and provide detailed information about the early and late stages of stimulus processing (Harrewijn et al., 2017; Luck, 2014). Later potentials, such as the P3 and the Late Positive Potential (LPP), index the allocation of attentional resources to process specific stimuli (Polich, 2003). In real-world, individuals are always processing information. They are continuously exposed to a wide array of stimuli in the environment and most of the time they are processing it involuntarily. Similarly, P3 and LPP are evoked and modulated by the stimulus itself, mapping automatic and involuntary processes triggered by simple exposure to it (Brown et al., 2012; Dennis & Hajcak, 2009). Many times they are observed before any active behavioral response. Therefore, studying P3 and LPP can help to understand processing alterations in anxiety such as attentional biases toward threats.

The P3 (Fig. 1a) is a positive brain waveform observed 300–500 ms after stimulus onset, with a topographical distribution at centroparietal regions. It reflects the shift and the amount of attention allocated to a target stimulus and its arousing emotional content. Specifically, has been associated with cognitive aspects of information processing, namely attention and memory-schemas updating (Harrewijn et al., 2017; Luck & Kappenman, 2011; Polich, 2003; 2007; van Dinteren et al., 2014). Interestingly, Ishida and colleagues (2018) demonstrated that P3 amplitudes were higher for negative-valenced words, which indicates that P3 is an involuntary attentional mechanism elicited by negative information (see also Thomas et al., 2006). This result unravels that attentional biases toward negative information can be observed in healthy subjects, reflecting adaptive evolutionary processes for processing immediate threats in the environment (Haselton et al., 2016).

The Late-Positive Potential (LPP; Fig. 1b) is a sustained neuronal response in the P3 time window, peaking around 400–700 ms at centroparietal regions after stimuli onset (Cuthbert et al., 2000; Polich, 2004). LPP is triggered by viewing affective pictures since larger amplitudes are reported for both pleasant and unpleasant stimuli compared to neutral ones (Harrewijn et al., 2017; Kujawa et al., 2015; Wauthia & Rossignol, 2016). Thus, LPP seems to be enhanced for emotional arousing pictures with high evolutionary significance (Schupp et al., 2004; 2006), and reflect the meaning of task-relevant stimuli instead of just physical stimuli characteristics (Johnson, 1988; Picton, 1992; Schupp et al., 2006). Research revealed indeed that LPP is sensitive to motivating emotional stimuli that automatically capture attention (Hajcak et al., 2010; McGhie et al., 2021). So, P3 and LPP seem to map automatic brain responses implicated in emotional and threat processing.

Individual findings regarding P3 and LPP modulation do not provide clear evidence in favor or against attentional-related threat bias in anxiety. Some studies argue that this bias can be found in both P3 and LPP time-windows (e.g., Leutgeb et al., 2009; Sewell et al., 2008; Zhang et al., 2017), while others do not (e.g., Fan et al., 2014; Metzger et al., 1997; Michalowski et al., 2009). In this context, the current study aims to provide a better understanding of P3 and LPP amplitude modulation, as elicited by negative-valenced stimuli across the anxiety spectrum.

For this purpose, a systematic search of the literature was conducted, to characterize P3 and LPP in disorders that can be clustered within the HiTOP fear and distress dimensions of the anxiety spectrum (Kotov et al., 2017). Two strategies were used: 1) within-group analyses to assess if negative stimuli elicit larger P3 and LPP amplitudes than positive and neutral stimuli, especially in the anxious group, 2) between-group analyses to evaluate if P3 and LPP amplitudes are higher in magnitude for anxious individuals than for controls, especially in negative stimuli. Several moderators were further included in the analysis following previous meta-analyses in this research field (Moser et al., 2013; Moser et al., 2016; Pasion & Barbosa, 2019; Pasion et al., 2019). Our hypotheses are exploratory given the discrepant results – but we can anticipate higher P3 and LPP amplitudes for negative stimuli, compared to neutral and positive stimuli, particularly in anxiety groups.

2. Method

This meta-analysis followed the PRISMA guidelines (Moher et al., 2009). All the between-group procedures were pre-registered at PROSPERO in 2020 (registration number: CRD42021219741). We included a within-subjects analysis following suggestions from reviewers.

2.1. Search and study selection strategy

Studies were selected via PUBMED and Web of Knowledge databases using the following search expressions limited to abstracts and topics: (anxi* OR phobi* OR "obsessive-compulsive" OR traum*) AND ("attention* bias*" OR threat* OR fear) AND ("event-related potentials" OR ERP OR "late positive potential" OR "LPP" OR P3 * OR LPC OR "late positive complex"). Mesh terms were used in PUBMED to optimize the search and the full search expression is reported in the Pre-registration. No filters for age or publication date were applied. The initial search was conducted in December 2020. Its update was made using the same search expression and databases in July 2021.

Initial screening of the articles was limited to title, abstract, and keywords. Two independent raters (CB and CP) assessed the eligibility of studies by taking into account the following inclusion criteria: (1) empirical study – the study had to report empirical findings; (2) ERP – the study had to include analyses of ERPs, specifically P3 and LPP; (3) clinical and subclinical anxiety – the study had to include samples assessed either for anxiety-related disorders (posttraumatic stress disorder, obsessive-compulsive disorder, generalized anxiety disorder, panic disorder, social anxiety disorder, and/or specific phobia) or for trait anxiety; (4) attentional bias –the study had to assess neuronal responses to attentional bias towards threat paradigms (e.g., Dot Probe Task – DPT; Oddball Paradigm – OP; Emotional Stroop Task – EST; free viewing tasks). All disagreements were examined by a third researcher (RP) and solved by consensus. All the included studies were analyzed for the following exclusion criteria: (5) repeated data: overlapping data across studies; (6) methodological issues: studies including tasks with an inadequate design for ERP analysis (i.e., two images presented at the same time; stimuli time window is not consistent with ERPs extraction timing parameters); (7) missing data: studies not describing the necessary parameters for computing effect sizes. No criteria for the ERPs time-windows and topography were imposed as we followed what was stated in the original studies.

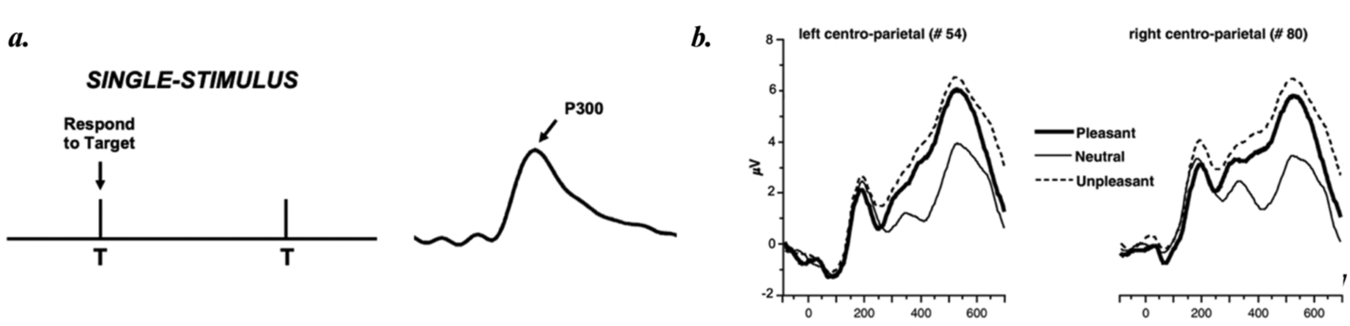

Fig. 1. a. P3 illustration (Polich, 2007) (Copyright © 2007, John Wiley and Sons. Reprinted with permission), **b.** LPP illustration (voltage interval adapted from Schupp et al., 2004) (Copyright © 2004, Elsevier. Reprinted with permission).

2.2. Data extracted

Two independent researchers (CB and CP) coded the main variables of interest, and a third researcher (RP) screened the database for any discrepancies.

2.3. Sample and subgroup characteristics

The codification of anxiety disorders was made following the common DSM nomenclature: generalized anxiety disorder; social anxiety disorder; specific phobia; panic disorder; posttraumatic stress disorder; obsessive-compulsive disorder; and unspecified anxiety disorder (DSM-5; American Psychiatric Association, 2013). These anxiety syndromes were then framed within the HiTOP Internalizing Spectrum, namely in the Fear and Distress subdimensions, and categorized accordingly (Kotov et al., 2017). The experimental group included clinical and subclinical samples, depending on the existence of a clinical diagnosis (e.g., DSM) or the assessment of anxiety symptoms based on self-reports, respectively.

2.4. Task and study characteristics

Tasks (Table 1) were labeled as follows: Dot Probe Task, Emotional Stroop Task, Oddball Paradigm, Eriksen Flanker Task, and Free Viewing Tasks. Even though these tasks are heterogeneous regarding what is required from the participants, they are homogeneous in the mechanism they elicit, i.e., automatic emotional processing of the stimulus content, and are all able to elicit P3 and LPP (even passive tasks).

For each task, the affective content of the stimulus being present was extracted: Neutral, Positive, Negative. Neutral stimuli included neutral words (e.g., hydrant, carpet) or neutral pictures (e.g., household items, flowers, neutral human faces). Positive stimuli included, for example, happy faces, cute animals, and babies. Negative stimuli encompassed all the threatening content that may elicit the attentional-threat bias and were further categorized as Relevant, Fear/Threat, or Unpleasant stimuli. Relevant stimuli referred to visual stimuli that were related to the diagnosis/symptoms of the anxious group (e.g., ordering images for OCD, spider pictures in phobia, war-related words in posttraumatic stress disorder), being considered disorder-congruent. Thus, labeling a stimulus as disorder-congruent depended on the samples' symptoms (e.g., the same stimulus could be considered relevant in one sample and fear/threat in another). Fear/Threat stimuli included life-threatening or feared pictures/words/faces that were more general and not disorder-relevant (e.g., pictures of physical assault, mutilated bodies, predators, angry faces). Unpleasant stimuli designated something disgusting/repulsive (e.g., poor hygiene, repulsive animals, faces displaying disgust) and sad (e.g., sad faces).

Table 1
Characteristics of the tasks used in the included studies.

Task	Description
Dot Probe Task – DPT (MacLeod et al., 1986)	Neutral and threat-related stimuli are presented simultaneously in threat-neutral pairs, followed by a probe appearing on the screen at either the location of neutral or threat-related stimuli. Subjects have to identify the location of the probe as fast and accurately as possible. In the present meta-analysis, ERPs modulation was locked to the dot.
Emotional Stroop Task – EST (Stroop, 1935)	Is a modified version of the classic Stroop Task that uses emotional words and neutral words. Participants have to name the color of the printed word while ignoring the semantic content of the word.
Oddball Paradigm	Standard and deviant/target stimuli are presented sequentially and randomly, with different probabilities (e.g., 80% for standards and 20% for deviants). Subjects have to respond by pressing a button for the targets or by answering the number of deviant stimuli in each trial.
Erisken Flanker Task (Eriksen & Eriksen, 1974)	In the classic flanker tasks, participants have to respond to a central target (e.g., letter H) and ignore congruent (e.g., HHHHH) or incongruent (e.g., SSHSS) flanking stimuli. An emotional variant of this task (e.g., Moser et al., 2008) uses emotional facial expressions (e.g., angry, happy, and neutral) as flanking stimuli.
Free Viewing Tasks	Free viewing tasks refer to paradigms where participants passively viewed/free viewed pictures with emotional content (e.g., faces displaying emotions), passively read words (e.g., trauma-related words, neutral words), or had to identify the emotion portrayed in faces (e.g., angry faces, sad faces, neutral faces).

2.5. P3 and LPP amplitudes (time-domain analysis)

For the between-subjects analyses, P3 and LPP amplitudes (means and standard deviations) observed in control and experimental groups were coded regarding each sample and condition, as well as *t* and *p*-values when between-group effects were available. For the within-subjects analyses, P3 and LPP amplitudes (means and standard deviations) were retrieved from the samples (anxious and controls separately) regarding each condition (stimulus type), as well as *t* and *p*-values when stimuli effects were available. The amplitudes referred to the electrode topographical region in which the amplitude difference between groups or stimuli was maximal (frontal, central, parietal, and occipital). Missing information was requested from corresponding authors. A total of 48 authors were contacted (response rate providing the requested data = 35.4%).

2.6. Data analysis

Since the purpose of the present study is to explore the attentional bias in P3 and LPP amplitudes modulation across the anxiety spectrum, we meta-analyzed different categories of stimuli (neutral, positive, and negative) within anxious and low-anxious groups, as well between groups. All effect sizes were computed from random-effects models, using the Comprehensive Meta-Analysis software (CMA 3.0; Biostat, USA).

Hedges' *g* (Hedges, 1981) was used to estimate the effect sizes. For the within-subjects analysis, effect sizes were extracted such that a positive *g* indicated that the negative stimuli exhibited enhanced P3 and LPP amplitudes compared to neutral or positive stimuli. The same applies to the positive-neutral contrast in which a positive *g* indicates that positive stimuli exhibited enhanced P3 and LPP amplitudes, whereas a negative *g* indicated reduced amplitudes, compared to neutral stimuli. For the between-subjects analysis, a positive *g* indicated that the anxiety group exhibited enhanced P3 and LPP amplitudes, while a negative *g* indicated reduced P3 and LPP amplitudes, compared to controls.

The calculation of the within-subjects effect size depends on the correlation values between conditions, as well as the means and standard deviations for each condition. However, such values were not reported in the included studies which poses a problem for the current meta-analysis since the magnitude of the effect size depends on whether the correlations between conditions vary (Ferreira-Santos, 2018; Morris & DeShon, 2002; Pasion et al., 2017). To assess if correlation values would change the reported effect size, a sensitivity analysis using a range of plausible correlations was conducted using small (0.20), moderated (0.50), and high correlations (0.80). No significant differences were found (cf. footnotes in the result section), so the reported statistics will refer to a moderated correlation coefficient (0.50) based on what is expected for ERP studies and datasets from our laboratory.

Recent meta-analytical normative guidelines for interpreting results in the individual differences research field (Funder & Ozer, 2019; Gignac & Szodorai, 2016) propose the following classification for correlation-based effect sizes: small ($r \geq 0.10$), medium ($r \geq 0.20$), and large ($r \geq 0.30$). As a result, these cut-off values were converted to between-group effect sizes - small ($g = 0.20$), medium ($g = 0.41$), and large ($g = 0.63$).

The variability between studies, i.e., the differences in effect sizes that are caused by other factors than chance (sampling error), was analyzed on overall effect sizes using the Q (Cochran, 1954) and the I^2 statistic (Higgins et al., 2003).

We conducted moderation analyses to examine which factors may influence the ERPs modulation (Age, Percentage of Females, Medication, Sample, Comorbidity, Electrode Topographical Region, ERP measure), and which factors may account for the main effect sizes (ERP, Task, HiTOP Internalizing Spectrum, Anxiety Disorders). For instance, meta-analytic literature in this field has shown that both types of moderators may have an impact on the main effect sizes (e.g., Clauss et al., 2022; Moran, 2016; Pasion et al.,; 2017).

More specifically, categorical-level moderation analyses were applied to the categorical variables of interest, namely: ERP (P3, LPP), Sample (community-dwelling, clinical), Medication (yes, no), Comorbidity (yes, no), Task (Free viewing, Dot Probe Task, Emotional Stroop Task, Oddball Paradigm, Eriksen Flanker Task), Electrode Topographical Region (all, central, centroparietal, frontal, parietooccipital, frontocentral, parietal), ERP measure (mean, peak amplitude), HiTOP Internalizing Spectrum (Fear, Distress), Anxiety disorders (general anxiety disorder, mixed anxiety symptoms, non-specified anxiety symptoms, obsessive-compulsive disorder, panic disorder, specific phobia, social anxiety disorder, posttraumatic stress disorder). In this sense, categorical variables were coded as level-statistical factors to examine the level-wise significance of these moderators. For continuous variables, a meta-regression was conducted for age and percentage of females to examine if studies with more discrepancies in gender and age would moderate the results. Lastly, Eggers's regression intercept (Egger et al., 1997) was used to calculate the publication bias.

3. Results

3.1. Search results

A total of 713 non-duplicated studies were found (Fig. 2). After the screening by title and abstract, 273 out of topic records were removed, and the remaining studies ($n = 440$) were assessed for eligibility criteria (abstract + full text). Thirty-five articles did not comply with criteria 1 (experimental study), 67 with criteria 2 (ERP), 198 with criteria 3 (anxiety assessment), and 88 with criteria 4 (attentional bias paradigms). The remaining 52 studies were assessed for exclusion criteria (full text). One study was removed by criteria 5 (repeated data), 3 were removed by criteria 6 (methodological issues), and 14 were excluded by criteria 7 (missing data) because the authors did not provide the requested data (e.g., mean and standard deviations were not reported, or the direction of the results was not clear). The interrater reliability was perfect (K =0.94).

Thirty-four articles were retrieved for the quantitative analysis (29 articles were included in both between and within-subjects analysis; 3 articles in between-subjects analysis only; and 2 articles in within-subjects analysis only; Fig. 2, and cf. Supplementary Material Table S1). Articles' publication year ranged from 1996 to 2021, 7 studies assessed youth samples (underaged), and no studies recruited elderly samples.

3.2. Sample characteristics

3.2.1. Within-subjects analysis

A total of 72 effects involving 1699 participants (58.47% females, $M_{age} = 21.41$) were analyzed to test P3 and LPP amplitudes differences between negative-, and neutral- and positive-valanced, both for anxious (38 studies, $n = 885$) and low-anxious samples (34 studies, $n = 814$).

3.2.2. Between-subjects analysis

A total of 37 studies involving 1631 participants (65.73% females, $M_{age} = 20.93$) were analyzed to test P3 and LPP amplitudes differences between anxious individuals ($n = 886$) and controls ($n = 745$).

3.3. Overall effect - within-subjects analysis

3.3.1. Negative-Neutral

3.3.1.1. Anxious samples. A total of 77 effects were included in the estimation of the overall negative-neutral effect. The overall effect[2] was statistically significant (i.e., enhanced P3 and LPP amplitudes; Fig. 3), $g = 0.513$, CI 95% [0.312, 0.715], $p < .001$, and affected by significant heterogeneity, $Q(29) = 175.4$, $p < .001$, $I^2 = 83.5$. When considering the negative categories in the model, we observed a medium effect in the Relevant subcondition, $g = 0.525$, CI 95% [0.257, 0.793], $p < .001$, a medium effect in the Fear/Threat subcondition, $g = 0.538$, CI 95% [0.369, 0.707], $p < .001$, and a large effect in the Unpleasant subcondition, $g = 0.642$, CI 95% [0.491, 0.793], $p < .001$. No evidence for publication bias was found on the overall effect, $b = 1.36$, $p = .344$.

3.3.2. Low-anxious samples

A total of 73 effects were included in the estimation of the meta-analytical overall effect for the negative-neutral comparison. The overall effect[3] was statistically significant (i.e., increased P3 and LPP amplitudes; Fig. 4), $g = 0.428$, CI 95% [0.255, 0.602], $p < .001$, and was also affected by significant heterogeneity, $Q(27) = 132.8$, $p < .001$, $I^2 = 79.7$. Concerning the negative categories in the model (unpleasant, fear/threat stimuli), we observed a medium effect in the Fear/Threat condition, $g = 0.457$, CI 95% [0.332, 0.582], $p < .001$, and a large effect in the Unpleasant condition, $g = 0.841$, CI 95% [0.613, 1.070], $p < .001$. No evidence for publication bias was found on the overall effect, $b = 2.09$, $p = .053$.

3.4. Negative - Positive

3.4.1. Anxious samples

A total of 22 effects were included in the negative-positive comparison. The overall effect[4] was statistically significant (i.e., increased P3 and LPP amplitudes; Fig. 5), $g = 0.246$, CI 95% [0.110, 0.382], $p < .001$. There was no evidence of heterogeneity, $Q(13) = 22.17$, $p = .053$, $I^2 = 41.4$, and publication bias, $b = -0.17$, $p = .918$. We observed a small effect in the Relevant subcondition, $g = 0.175$, CI 95% [0.032, 0.318], $p = .016$, and a small effect in the Fear/Threat subcondition, $g = 0.247$,

[2] The sensitivity analysis did not reveal major alterations in the reported effect size, using either a 0.20, $g = 0.517$, CI 95% [0.314, 0.721], $p < .001$, a 0.50, $g = 0.513$, CI 95% [0.312, 0.715], $p < .001$, or a 0.8 correlation coefficient, $g = 0.477$, CI 95% [0.281, 0.674], $p < .001$. These results indicate that variation in the actual correlation value would not substantially modify the subsequent analyses, and thus a 0.50 correlation will be used as reference for all analyses.

[3] The sensitivity analysis did not reveal major alterations in the reported effect size, using either a 0.20, $g = 0.412$, CI 95% [0.240, 0.584], $p < .001$, a 0.50, $g = 0.428$, CI 95% [0.255, 0.602], $p < .001$, or a 0.8 correlation coefficient, $g = 0.443$, CI 95% [0.270, 0.616], $p < .001$. These results indicate that variation in the actual correlation value would not substantially modify the subsequent analyses, and thus a 0.50 correlation will be used as reference for all analyses.

[4] The sensitivity analysis did not reveal major alterations in the reported effect size, using either a 0.20, $g = 0.246$, CI 95% [0.113, 0.380], 0.721], $p < .001$, a 0.50, $g = 0.246$, CI 95% [0.110, 0.382], $p < .001$, or a 0.8 correlation coefficient, $g = 0.240$, CI 95% [0.106, 0.374], $p < .001$. These results indicate that variation in the actual correlation value would not substantially modify the subsequent analyses, and thus a 0.50 correlation will be used as reference for all analyses.

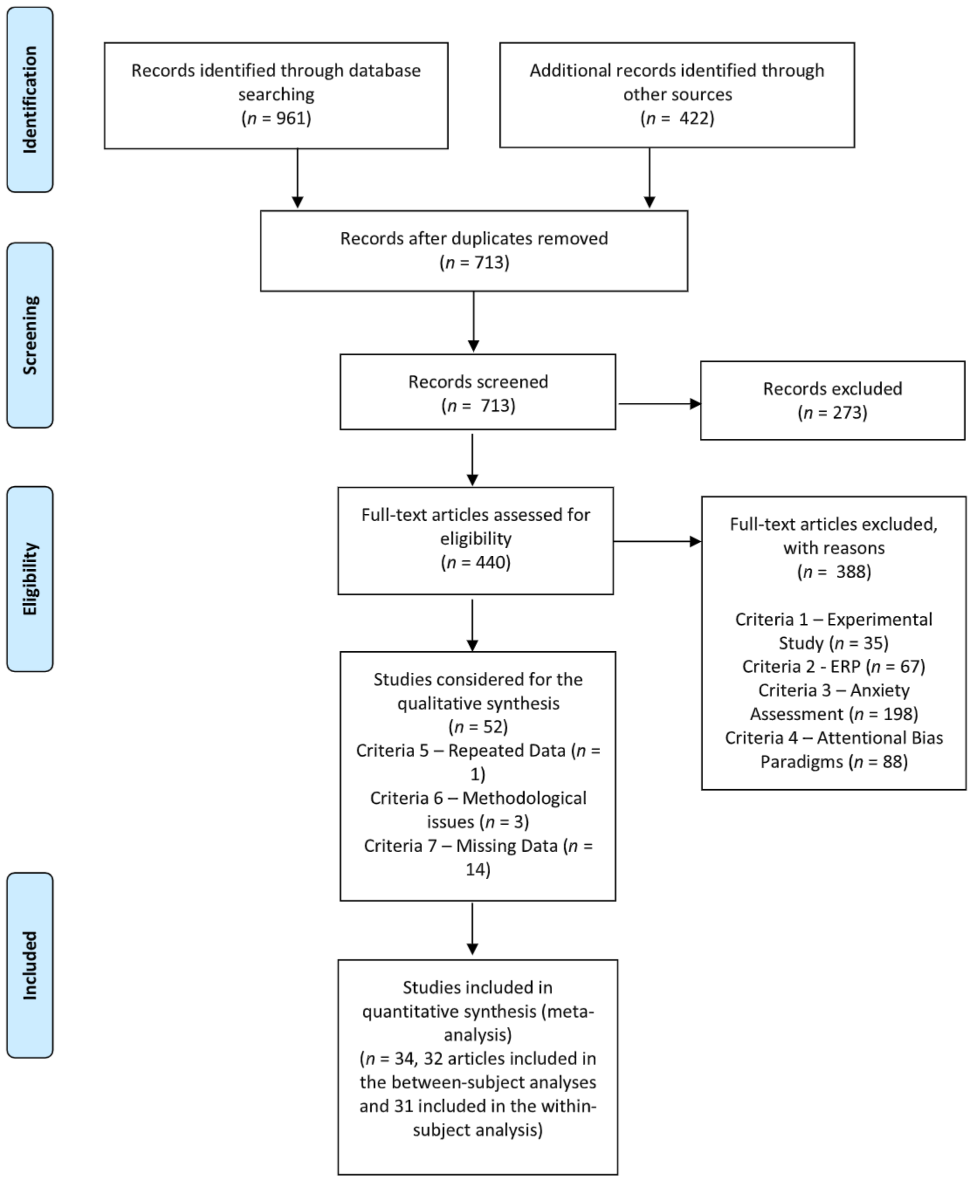

Fig. 2. PRISMA flow diagram.

CI 95% [0.114, 0.390], $p < .001$, but not in the Unpleasant subcondition, $g = 0.055$, CI 95% [− 0.357, 0.467], $p = .794$.

3.5. *Low-anxious samples*

This comparison included 20 effects. The overall effect[5] was statistically significant (i.e., enhanced P3 and LPP amplitudes; Fig. 6), $g = 0.162$, CI 95% [0.036, 0.288], $p = .012$. Again, there was no significant heterogeneity, $Q(12) = 16.6$, $p < .167$, $I^2 = 27.5$, nor publication bias, $b = 1.34$, $p = .457$. We observed a small effect in the Fear/Threat condition, $g = 0.116$, CI 95% [0.007, 0.224], $p = .038$, but not in the Unpleasant condition, $g = 0.247$, CI 95% [− 0.079,0.574], $p = .138$.

3.6. *Positive-Neutral*

3.6.1. *Anxious samples*

A total of 19 effects were included in the estimation of this meta-analytical effect. The overall effect[6] was statistically significant (i.e., higher P3 and LPP amplitudes; Fig. 7), $g = 0.408$, CI 95% [0.096, 0.721], $p = .010$. The overall effect was affected by significant heterogeneity, $Q(12) = 89.3$, $p < .001$, $I^2 = 86.6$, but there was no publication bias, $b = 2.57$, $p = .453$.

[5] The sensitivity analysis did not reveal major alterations in the reported effect size, using either a 0.20, $g = 00.159$, CI 95% [0.026, 0.293], $p = .020$, a 0.50, $g = 0.162$, CI 95% [0.036, 0.288], $p = .012$, or a 0.8 correlation coefficient, $g = 0.160$, CI 95% [0.043, 0.295], $p = .008$. These results indicate that variation in the actual correlation value would not substantially modify the subsequent analyses, and thus a 0.50 correlation will be used as reference for all analyses.

[6] The sensitivity analysis did not reveal major alterations in the reported effect size, using either a 0.20, $g = 0.402$, CI 95% [0.086, 0.719], $p = .013$, a 0.50, $g = 0.408$, CI 95% [0.096, 0.721], $p = .010$, or a 0.8 correlation coefficient, $g = 0.403$, CI 95% [0.101, 0.705, $p = .009$. These results indicate that variation in the actual correlation value would not substantially modify the subsequent analyses, and thus a 0.50 correlation will be used as reference for all analyses.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Attias et al.	0.186	0.217	0.047	-0.239	0.611	0.859	0.390
Metzger et al.	0.530	0.326	0.106	-0.109	1.169	1.627	0.104
Pauli et al.	0.830	0.294	0.086	0.254	1.406	2.827	0.005
Blomhoff et al.	0.198	0.282	0.079	-0.353	0.750	0.705	0.481
Kolassa et al.	0.463	0.247	0.061	-0.020	0.947	1.880	0.060
Schienle et al.	1.022	0.287	0.082	0.459	1.585	3.558	0.000
Michalowski et al.	1.763	0.352	0.124	1.073	2.453	5.006	0.000
Leutgeb et al.	0.899	0.246	0.061	0.417	1.381	3.654	0.000
Leutgeb & Köchel	0.994	0.349	0.122	0.310	1.679	2.847	0.004
Weinberg & Hajcak	0.532	0.225	0.051	0.090	0.974	2.360	0.018
Leutgeb & Schäffer	1.047	0.291	0.085	0.476	1.618	3.594	0.000
Grasso et al.	0.331	0.226	0.051	-0.112	0.775	1.465	0.143
Fan et al.	2.015	0.310	0.096	1.407	2.622	6.498	0.000
Weinberg et al.	1.455	0.199	0.040	1.064	1.846	7.296	0.000
Zhang et al.	-0.480	0.744	0.553	-1.938	0.978	-0.646	0.518
Shah et al.	0.131	0.229	0.052	-0.317	0.580	0.574	0.566
Dayan-Riva et al.	-0.279	0.226	0.051	-0.722	0.163	-1.237	0.216
Nyun Kim et al.	1.466	0.316	0.100	0.847	2.085	4.640	0.000
Sandre et al.	0.417	0.196	0.038	0.034	0.801	2.133	0.033
Keil et al.	0.189	0.175	0.030	-0.153	0.531	1.081	0.280
Klein et al.	0.174	0.158	0.025	-0.153	0.482	1.102	0.270
Letkiewicz et al.	0.525	0.200	0.040	0.133	0.917	2.622	0.009
Sass et al.	0.078	0.201	0.040	-0.315	0.471	0.389	0.697
Kujawa et al.	0.892	0.161	0.026	0.577	1.207	5.543	0.000
Lobo et al.	1.058	0.272	0.074	0.525	1.592	3.889	0.000
Thomas et al.	-0.056	0.215	0.046	-0.477	0.366	-0.259	0.796
Meynadasy et al.	0.392	0.111	0.012	0.173	0.610	3.517	0.000
Campbell et al.	-0.100	0.159	0.025	-0.412	0.212	-0.626	0.531
Leutgeb & Schienle	-1.881	0.456	0.208	-2.774	-0.987	-4.126	0.000
Sass & Evans	0.071	0.233	0.054	-0.385	0.527	0.305	0.760
	0.513	0.103	0.011	0.312	0.715	4.991	0.000

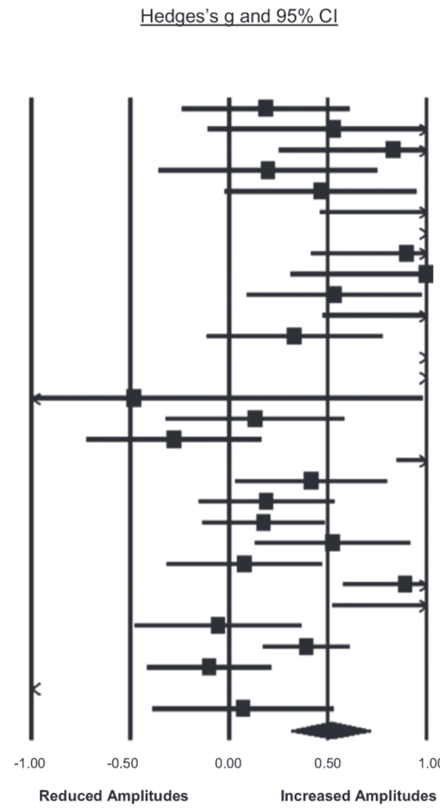

Fig. 3. Anxious samples: negative - neutral forest plot. The diamond in the forest plot indicates the average effect size.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Attias et al.	1.054	0.272	0.074	0.522	1.587	3.879	0.000
Metzger et al.	0.625	0.321	0.103	-0.005	1.254	1.945	0.052
Pauli et al.	-1.111	0.319	0.102	-1.736	-0.486	-3.483	0.000
Blomhoff et al.	0.241	0.306	0.094	-0.359	0.842	0.788	0.431
Kolassa et al.	0.397	0.245	0.060	-0.083	0.876	1.622	0.105
Schienle et al.	0.914	0.289	0.083	0.348	1.479	3.166	0.002
Michalowski et al.	1.256	0.276	0.076	0.716	1.797	4.554	0.000
Leutgeb et al.	0.739	0.246	0.061	0.257	1.222	3.001	0.003
Leutgeb & Köchel	0.673	0.294	0.086	0.097	1.250	2.290	0.022
Weinberg &Hajcak	1.422	0.279	0.078	0.875	1.969	5.093	0.000
Leutgeb & Schäffer	1.048	0.288	0.083	0.483	1.613	3.635	0.000
Grasso et al.	0.276	0.224	0.050	-0.164	0.715	1.230	0.219
Fan et al.	0.290	0.185	0.034	-0.071	0.652	1.573	0.116
Weinberg et al.	0.965	0.210	0.044	0.552	1.377	4.584	0.000
Zhang et al.	3.552	0.863	0.745	1.861	5.244	4.116	0.000
Shah et al.	-0.215	0.228	0.052	-0.661	0.232	-0.942	0.346
Dayan-Riva et al.	0.158	0.184	0.034	-0.202	0.519	0.861	0.389
Nyun Kim et al.	-0.144	0.202	0.041	-0.540	0.253	-0.709	0.478
Sandre et al.	0.298	0.145	0.021	0.006	0.572	1.998	0.046
Keil et al.	0.191	0.172	0.029	-0.146	0.527	1.111	0.266
Klein et al.	-0.016	0.163	0.027	-0.337	0.304	-0.099	0.921
Letkiewicz et al.	-0.028	0.194	0.038	-0.408	0.352	-0.145	0.884
Sass et al.	0.102	0.164	0.027	-0.219	0.422	0.621	0.534
Kujawa et al.	0.922	0.193	0.037	0.543	1.302	4.769	0.000
Lobo et al.	0.791	0.233	0.054	0.335	1.247	3.400	0.001
Thomas et al.	0.219	0.217	0.047	-0.207	0.645	1.006	0.314
Meynadasy et al.	0.260	0.078	0.006	0.106	0.414	3.315	0.001
Campbell et al.	-0.083	0.231	0.054	-0.537	0.370	-0.360	0.719
	0.428	0.088	0.008	0.255	0.602	4.843	0.000

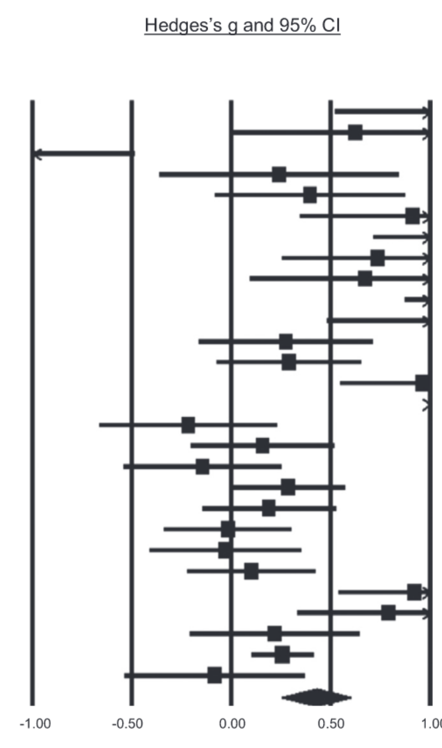

Fig. 4. Low-anxious samples: negative - neutral forest plot. The diamond in the forest plot indicates the average effect size.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Metzger et al.	-0.149	0.303	0.092	-0.743	0.445	-0.492	0.623
Blomhoff et al.	0.135	0.280	0.078	-0.414	0.683	0.481	0.631
Moser et al.	0.337	0.216	0.047	-0.087	0.761	1.559	0.119
Michalowski et al.	-0.047	0.215	0.046	-0.469	0.376	-0.216	0.829
Weinberg & Hajcak	0.055	0.210	0.044	-0.357	0.467	0.261	0.794
Grasso et al.	0.402	0.229	0.053	-0.047	0.851	1.755	0.079
Fan et al.	0.847	0.205	0.042	0.444	1.249	4.121	0.000
Weinberg et al.	0.341	0.142	0.020	0.063	0.620	2.404	0.016
Keil et al.	0.268	0.176	0.031	-0.077	0.612	1.525	0.127
Klein et al.	0.291	0.159	0.025	-0.020	0.603	1.834	0.067
Letkiewicz et al.	0.636	0.206	0.042	0.233	1.040	3.090	0.002
Sass et al.	-0.007	0.200	0.040	-0.400	0.385	-0.037	0.970
Kujawa et al.	0.028	0.136	0.018	-0.238	0.295	0.208	0.835
Sass & Evans	0.158	0.233	0.054	-0.298	0.614	0.678	0.498
	0.246	0.069	0.005	0.110	0.382	3.553	0.000

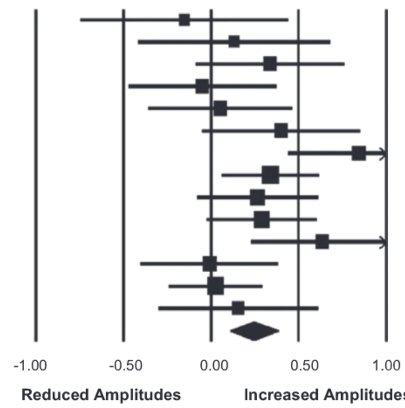

Fig. 5. Anxious samples: negative - positive forest plot. The diamond in the forest plot indicates the average effect size.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Metzger et al.	0.342	0.299	0.089	-0.245	0.928	1.142	0.253
Blomhoff et al.	0.523	0.325	0.106	-0.115	1.161	1.608	0.108
Moser et al.	0.076	0.210	0.044	-0.336	0.488	0.360	0.719
Michalowski et al.	-0.508	0.218	0.047	-0.934	-0.081	-2.331	0.020
Weinberg & Hajcak	0.409	0.202	0.041	0.013	0.805	2.024	0.043
Grasso et al.	0.325	0.226	0.051	-0.117	0.768	1.440	0.150
Fan et al.	0.128	0.181	0.033	-0.228	0.483	0.704	0.481
Weinberg et al.	0.051	0.173	0.030	-0.287	0.389	0.297	0.767
Keil et al.	0.386	0.176	0.031	0.040	0.732	2.187	0.029
Klein et al.	0.143	0.160	0.026	-0.170	0.456	0.895	0.371
Letkiewicz et al.	0.332	0.199	0.040	-0.059	0.722	1.665	0.096
Sass et al.	0.052	0.163	0.027	-0.268	0.372	0.318	0.751
Kujawa et al.	0.120	0.162	0.026	-0.196	0.437	0.744	0.457
	0.162	0.064	0.004	0.036	0.288	2.525	0.012

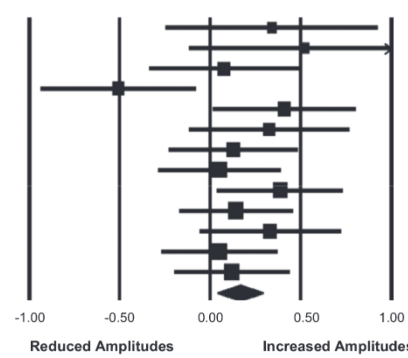

Fig. 6. Low-anxious samples: negative-positive comparison forest plot. The diamond in the forest plot indicates the average effect size.

3.6.2. Low-anxious samples

A total of 15 effects were included, showing a non-significant effect[7] (Fig. 8), $g = 0.303$, CI 95% [− 0.017, 0.623], $p = .064$. The overall effect was affected by significant heterogeneity, $Q(11) = 80.3$, $p < .001$, $I^2 = 86.3$, but no evidence for publication bias was found, $b = 4.45$, $p = .207$.

3.6.3. Overall effects – between-subjects analysis

3.6.3.1. Neutral stimuli. A total of 47 effects were included for estimating the overall effect for the neutral stimuli (Fig. 9). It was not significant, $g = -0.025$, CI 95% [− 0.297, 0.246], $p = .856$, showing no differences between groups. Significant heterogeneity was reported, $Q(27) = 160.53$, $p < .001$, $I^2 = 83.2$, but there was no publication bias, $b = -1.60$, $p = .472$.

3.6.3.2. Positive stimuli. A total of 16 effects were included for positive stimuli (Fig. 10). The overall effect was non-significant, $g = 0.241$, CI 95% [− 0.217, 0.699], $p = .302$, and displayed significant heterogeneity, $Q(12) = 101.3$, $p < .001$, $I^2 = 88.2$. No evidence for publication bias was found, $b = 1.90$, $p = .58$.

3.6.3.3. Negative stimuli. A total of 81 effects were extracted. Despite the expected positive direction of the results (i.e. higher P3 and LPP amplitudes; Fig. 11), the overall effect did not reach significance, $g = 0.159$, CI 95% [− 0.103, 0.421], $p = .235$.

Regarding the negative subcategories in the model (relevant, unpleasant, fear/threat stimuli), we observed a small to medium effect (i.e., higher P3 and LPP amplitudes) in the Relevant subcondition, $g = 0.298$, CI 95% [0.020, 0.576], $p = .036$, but not in other subconditions (Fear/Threat: $g = 0.036$, CI 95% [−0.197, 0.268], $p = .763$; Unpleasant: $g = 0.171$, CI 95% [−0.073, 0.415], $p = .169$). The overall effect was affected by significant heterogeneity, $Q(31) = 191.9$, $p < .001$, $I^2 = 83.8$, but there was no publication bias, $b = -0.22$, $p = .913$.

[7] The sensitivity analysis did not reveal major alterations in the reported effect size, using either a 0.20, $g = 0.297$, CI 95% [− 0.027, 0.621], $p = .073$, a 0.50, $g = 0.428$, CI 95% [0.255, 0.602], $p < .001$, or a 0.8 correlation coefficient, $g = 0.301$, CI 95% [− 0.009, 0.611], $p = .057$. These results indicate that variation in the actual correlation value would not substantially modify the subsequent analyses, and thus a 0.50 correlation will be used as reference for all analyses.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Attias et al.	0.186	0.217	0.047	-0.239	0.611	0.859	0.390
Metzger et al.	0.530	0.326	0.106	-0.109	1.169	1.627	0.104
Pauli et al.	0.830	0.294	0.086	0.254	1.406	2.827	0.005
Blomhoff et al.	0.198	0.282	0.079	-0.353	0.750	0.705	0.481
Kolassa et al.	0.463	0.247	0.061	-0.020	0.947	1.880	0.060
Schienle et al.	1.022	0.287	0.082	0.459	1.585	3.558	0.000
Michalowski et al.	1.763	0.352	0.124	1.073	2.453	5.006	0.000
Leutgeb et al.	0.899	0.246	0.061	0.417	1.381	3.654	0.000
Leutgeb & Köchel	0.994	0.349	0.122	0.310	1.679	2.847	0.004
Weinberg & Hajcak	0.532	0.225	0.051	0.090	0.974	2.360	0.018
Leutgeb & Schäffer	1.047	0.291	0.085	0.476	1.618	3.594	0.000
Grasso et al.	0.331	0.226	0.051	-0.112	0.775	1.465	0.143
Fan et al.	2.015	0.310	0.096	1.407	2.622	6.498	0.000
Weinberg et al.	1.455	0.199	0.040	1.064	1.846	7.296	0.000
Zhang et al.	-0.480	0.744	0.553	-1.938	0.978	-0.646	0.518
Shah et al.	0.131	0.229	0.052	-0.317	0.580	0.574	0.566
Dayan-Riva et al.	-0.279	0.226	0.051	-0.722	0.163	-1.237	0.216
Nyun Kim et al.	1.466	0.316	0.100	0.847	2.085	4.640	0.000
Sandre et al.	0.417	0.196	0.038	0.034	0.801	2.133	0.033
Keil et al.	0.189	0.175	0.030	-0.153	0.531	1.081	0.280
Klein et al.	0.174	0.158	0.025	-0.135	0.482	1.102	0.270
Letkiewicz et al.	0.525	0.200	0.040	0.133	0.917	2.622	0.009
Sass et al.	0.078	0.201	0.040	-0.315	0.471	0.389	0.697
Kujawa et al.	0.892	0.161	0.026	0.577	1.207	5.543	0.000
Lobo et al.	1.058	0.272	0.074	0.525	1.592	3.889	0.000
Thomas et al.	-0.056	0.215	0.046	-0.477	0.366	-0.259	0.796
Meynadasy et al.	0.392	0.111	0.012	0.173	0.610	3.517	0.000
Campbell et al.	-0.100	0.159	0.025	-0.412	0.212	-0.626	0.531
Leutgeb & Schienle	-1.881	0.456	0.208	-2.774	-0.987	-4.126	0.000
Sass & Evans	0.071	0.233	0.054	-0.385	0.527	0.305	0.760
	0.513	0.103	0.011	0.312	0.715	4.991	0.000

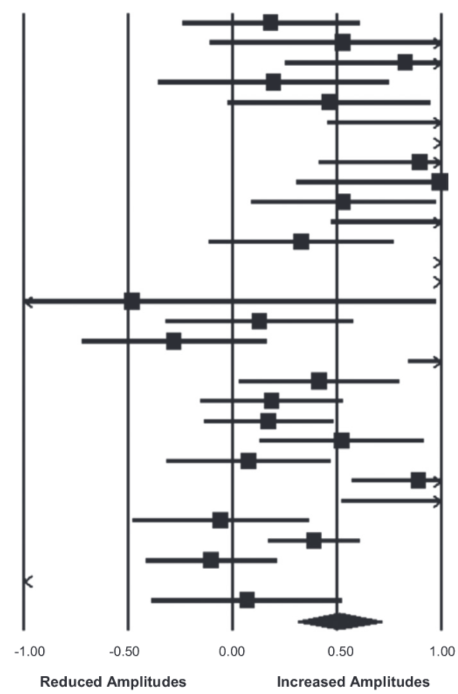

Fig. 7. Anxious samples: positive-neutral comparison forest plot. The diamond in the forest plot indicates the average effect size.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Metzger et al.	0.304	0.297	0.088	-0.279	0.886	1.022	0.307
Blomhoff et al.	-0.544	0.327	0.107	-1.185	0.098	-1.661	0.097
Michalowski et al.	1.689	0.320	0.103	1.062	2.317	5.275	0.000
Weinberg & Hajcak	1.041	0.243	0.059	0.564	1.518	4.280	0.000
Grasso et al.	-0.034	0.220	0.048	-0.465	0.396	-0.157	0.876
Fan et al.	0.156	0.182	0.033	-0.200	0.513	0.859	0.391
Weinberg et al.	1.185	0.227	0.052	0.739	1.630	5.211	0.000
Keil et al.	-0.212	0.172	0.030	-0.549	0.126	-1.230	0.219
Klein et al.	-0.081	0.160	0.026	-0.394	0.233	-0.505	0.614
Letkiewicz et al.	-0.320	0.199	0.040	-0.710	0.070	-1.609	0.108
Sass et al.	0.049	0.163	0.027	-0.271	0.369	0.301	0.763
Kujawa et al.	0.595	0.175	0.031	0.252	0.938	3.397	0.001
	0.303	0.163	0.027	-0.017	0.623	1.855	0.064

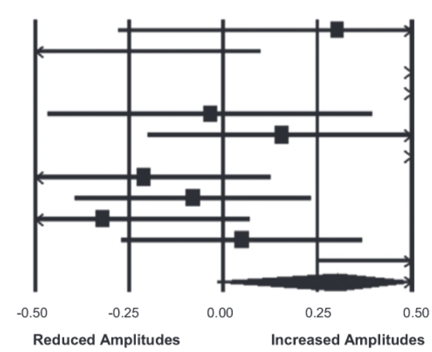

Fig. 8. Low-anxious samples: positive-neutral comparison forest plot. The diamond in the forest plot indicates the average effect size.

3.7. Moderation analysis

3.7.1. Age

Age was a non-significant moderator across all the analyses (cf., Tables S2, S4, S6, and S8).

3.7.2. Gender

Only in the between-group analysis, the percentage of females moderated the overall results in the negative category such that P3 and LPP amplitudes increased with the samples' percentage of females (cf., Tables S2, S4, S6, and S8).

3.7.3. Medication

Medication moderated the findings in some between- and within-subjects analyses (cf. Tables S3, S5, S7, and S9) – overall, unmedicated samples exhibited more consistent positive effects (i.e., higher P3 and LPP amplitudes).

3.7.4. Comorbidity

Comorbidity was a significant moderator across analyses (cf. Tables S3, S5, S7, and S9). For most of the computed effects, larger and significant effects (i.e., enhanced P3 and LPP amplitudes) were found for samples exhibiting no comorbidities with other disorders (e.g., depression-related symptoms).

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Michalowski et al.	-0.132	0.300	0.090	-0.721	0.457	-0.440	0.660
Metzger et al.	-2.025	0.548	0.301	-3.099	-0.950	-3.693	0.000
Fan et al.	3.794	0.430	0.185	2.951	4.637	8.822	0.000
Shah et al.	-0.689	0.336	0.113	-1.347	-0.031	-2.051	0.040
Leutgeb et al.	0.255	0.303	0.092	-0.340	0.849	0.840	0.401
Zhang et al.	-2.754	0.488	0.238	-3.709	-1.798	-5.648	0.000
Pauli et al.	-0.105	0.356	0.126	-0.801	0.592	-0.294	0.769
Letkiewicz et al.	-0.013	0.273	0.075	-0.549	0.522	-0.049	0.961
Attias et al.	1.314	0.343	0.118	0.642	1.986	3.831	0.000
Weinberg et al.	-0.146	0.224	0.050	-0.584	0.293	-0.651	0.515
Dayan-Riva et al.	0.343	0.229	0.052	-0.105	0.792	1.501	0.133
Weinberg & Hajcak	0.325	0.293	0.086	-0.249	0.889	1.109	0.267
Kolassa et al.	-0.050	0.320	0.103	-0.677	0.578	-0.155	0.877
Schienle et al.	-0.494	0.331	0.110	-1.143	0.156	-1.490	0.136
Blomhoff et al	-0.517	0.438	0.192	-1.376	0.342	-1.180	0.238
Nyun Kim et al.	-0.569	0.306	0.094	-1.170	0.031	-1.858	0.063
Leutgeb & Schäffer	0.133	0.326	0.106	-0.506	0.773	0.408	0.683
Sandre et al.	0.130	0.237	0.056	-0.335	0.595	0.548	0.584
Keil et al.	0.254	0.246	0.061	-0.229	0.737	1.031	0.302
Klein et al.	0.255	0.225	0.051	-0.187	0.696	1.131	0.258
Leutgeb & Köchel	-0.055	0.368	0.135	-0.775	0.666	-0.148	0.882
Grasso et al.	0.050	0.318	0.101	-0.572	0.673	0.159	0.874
Kujawa et al.	-0.196	0.213	0.045	-0.613	0.221	-0.920	0.358
Lobo et al.	-0.256	0.301	0.091	-0.847	0.335	-0.849	0.396
Thomas et al.	-0.123	0.310	0.096	-0.732	0.485	-0.396	0.692
Meynadasy et al.	0.248	0.304	0.092	-0.348	0.844	0.816	0.415
Campbell et al.	-0.279	0.289	0.083	-0.845	0.287	-0.966	0.334
Sass et al.	-0.104	0.263	0.069	-0.619	0.411	-0.396	0.692
	-0.025	0.139	0.019	-0.297	0.246	-0.182	0.856

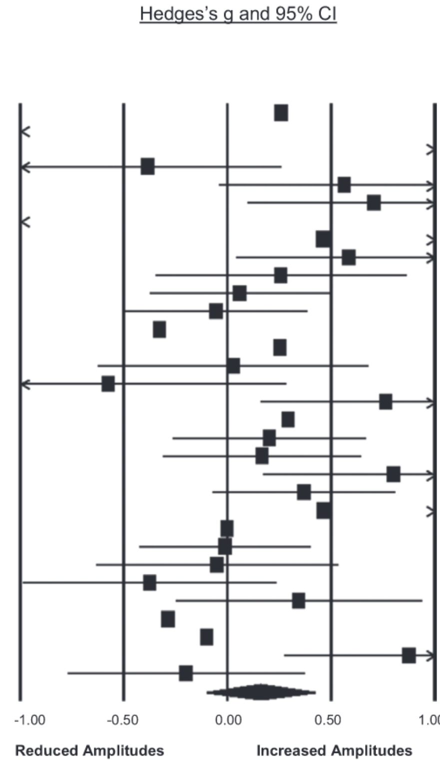

Fig. 9. Neutral stimuli: forest plot. The diamond in the forest plot indicates the average effect size.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Statistics for each study						
Metzger et al.	-1.928	0.539	0.290	-2.984	-0.872	-3.577	0.000
Blomhoff et al.	-0.313	0.433	0.188	-1.162	0.537	-0.722	0.470
Moser et al.	0.433	0.306	0.094	-0.168	1.033	1.412	0.158
Michalowski et al.	-0.228	0.301	0.091	-0.818	0.362	-0.758	0.448
Weinberg & Hajcak	-0.007	0.291	0.085	-0.577	0.563	-0.024	0.981
Grasso et al.	0.066	0.318	0.101	-0.557	0.689	0.208	0.835
Fan et al.	4.547	0.487	0.237	3.593	5.502	9.334	0.000
Weinberg et al.	0.211	0.224	0.050	-0.228	0.650	0.943	0.346
Keil et al.	0.282	0.247	0.061	-0.201	0.766	1.146	0.252
Klein et al.	0.193	0.225	0.051	-0.248	0.633	0.856	0.392
Letkiewicz et al.	0.060	0.273	0.075	-0.476	0.596	0.221	0.825
Kujawa et al.	0.089	0.213	0.045	-0.328	0.505	0.417	0.677
Sass et al.	-0.042	0.263	0.069	-0.557	0.473	-0.161	0.872
	0.241	0.234	0.055	-0.217	0.699	1.033	0.302

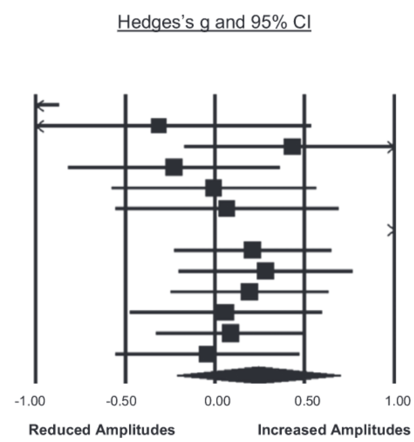

Fig. 10. Positive stimuli: forest plot. The diamond in the forest plot indicates the average effect size.

3.7.5. *Sample type*

The sample type further moderated the findings in between-group analysis (cf. Table S9): while no effect was found for clinical samples, a small effect (i.e., increased P3 and LPP amplitudes) was found for community-dwelling samples. The opposite pattern was found in within-analysis (cf. Tables S3, S5, and S7) where overall both sample types were significant moderators with approximate effect sizes. Nonetheless, in the positive-neutral comparison, a medium effect (i.e., higher P3 and LPP amplitudes) was found only for clinical samples.

3.7.6. *HiTOP dimensions*

The HiTOP dimensions that comprise the Internalizing Spectrum were a significant moderator. Despite no significant effects for the Distress Subfactor in between-group analysis, a significant effect was reported for the Fear factor for negative stimuli (cf. Table S9). More specifically, Specific Phobias and Social Anxiety Disorder seem to account for this result (medium effect, i.e., higher P3 and LPP amplitudes). A large effect (i.e., enhanced P3 and LPP amplitudes) was also found in Specific Phobia in the within negative-neutral comparison (cf. Table S3). Fear and Distress were both significant moderators in the negative-positive comparison (cf. Table S5). Small to medium effects (i.e., higher P3 and LPP amplitudes) were reported for distress dimensions - Post-Traumatic Stress Disorder and Obsessive-Compulsive Disorder – in within-groups analyses (cf. Tables S3, S5, and S7).

3.7.7. *Task*

In between-group analysis (cf. Table S9), tasks did not moderate the findings. The significant results in the Flanker and Dot Probe were

Study name	Statistics for each study						
	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Michalowski et al	0.260	0.304	0.092	-0.336	0.856	0.855	0.392
Metzger et al.	-2.025	0.548	0.301	-3.100	-0.951	-3.694	0.000
Fan et al.	5.411	0.556	0.309	4.322	6.501	9.734	0.000
Shah et al.	-0.385	0.330	0.109	-1.032	0.262	-1.166	0.244
Leutgeb et al.	0.565	0.310	0.096	-0.043	1.174	1.820	0.069
Moser et al.	0.708	0.312	0.098	0.096	1.321	2.267	0.023
Zhang et al.	-3.792	0.590	0.348	-4.949	-2.635	-6.424	0.000
Pauli et al.	0.460	0.360	0.130	-0.246	1.167	1.277	0.202
Letkiewicz et al.	0.586	0.279	0.078	0.039	1.134	2.099	0.036
Attias et al.	0.259	0.311	0.097	-0.351	0.896	0.832	0.406
Weinberg et al.	0.060	0.223	0.050	-0.378	0.498	0.269	0.788
Dayan-Riva et al.	-0.054	0.227	0.052	-0.500	0.391	-0.239	0.811
Weinberg & Hajcak	-0.328	0.293	0.086	-0.902	0.246	-1.119	0.263
Kolassa et al.	0.255	0.323	0.104	-0.378	0.888	0.790	0.430
Schienle et al.	0.028	0.335	0.112	-0.629	0.684	0.083	0.934
Blomhoff et al.	-0.576	0.440	0.194	-1.439	0.286	-1.309	0.190
Nyum Kim et al.	0.765	0.311	0.097	0.155	1.375	2.459	0.014
Leutgeb & Schäfer	0.294	0.330	0.109	-0.353	0.941	0.891	0.373
Sandre et al.	0.203	0.239	0.057	-0.265	0.671	0.848	0.396
Keil et al.	0.168	0.246	0.060	-0.313	0.650	0.685	0.493
Leutgeb & Sarlo	0.802	0.323	0.104	0.169	1.435	2.483	0.013
Klein et al.	0.370	0.226	0.051	-0.074	0.813	1.634	0.102
Leutgeb & Köchel	0.464	0.380	0.145	-0.281	1.209	1.220	0.223
Grasso et al.	-0.002	0.318	0.101	-0.624	0.621	-0.005	0.996
Kujawa et al.	-0.010	0.213	0.045	-0.427	0.406	-0.049	0.961
Lobo et al.	-0.050	0.300	0.090	-0.638	0.539	-0.166	0.868
Thomas et al.	-0.375	0.313	0.098	-0.989	0.240	-1.195	0.232
Meynadasy et al.	0.345	0.305	0.093	-0.253	0.943	1.131	0.258
Campbell et al.	-0.286	0.289	0.083	-0.852	0.281	-0.989	0.323
Sass et al.	-0.101	0.263	0.069	-0.616	0.415	-0.382	0.702
Scharmüller et al.	0.877	0.309	0.096	0.270	1.483	2.833	0.005
Zhang & Dong	-0.199	0.294	0.086	-0.775	0.376	-0.678	0.497
	0.159	0.134	0.018	-0.103	0.421	1.187	0.235

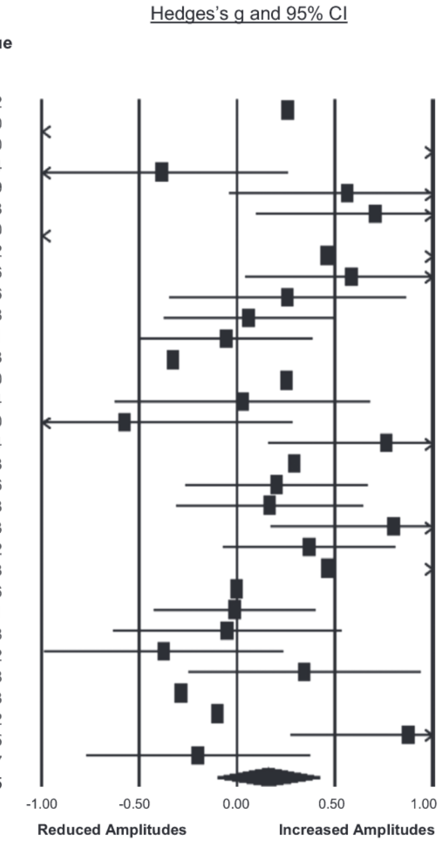

Fig. 11. Negative stimuli: forest plot. The diamond in the forest plot indicates the average effect size.

retrieved from one unique effect. In within-group analyses (cf. Tables S3, S5, and S7), effects were consistently larger, with enhanced P3 and LPP amplitudes, and more significant for Free Viewing Tasks, followed by medium effects for Emotional Stroop and a small effect for the Oddball Paradigm.

3.7.8. *ERP measurement*

ERP type (P3, LPP) did not moderate the findings in both analyses (cf. Tables S3, S5, S7, and S9). Overall, mean amplitude measurements yielded larger and more significant effects than peak amplitudes (i.e., increased P3 and LPP amplitudes; cf. Tables S3, S5, S7, and S9). The topographical region from where the P3 and LPP were extracted showed greater variability, but parietal regions were more systematically involved in higher P3 and LPP amplitudes (cf. Tables S3, S5, S7, and S9).

4. Discussion

Behavioral data highlight the importance of the attentional-threat bias in anxiety. However, systematic analyses of the literature are lacking when examining the brain neuronal activation that underpin the attentional bias toward threat in anxiety. The present meta-analytic study aimed to address this gap in the literature by examining P3 and LPP amplitude modulation. 34 studies were included in between ($n = 1631$) and within-groups ($n = 1699$) analytical strategies. Overall effects were calculated for each stimulus category (neutral, positive, and negative), whilst also considering important moderators.

4.1. *Overall effects*

4.1.1. *Within-subjects analysis*

In anxious populations, significant overall effects were found for negative-neutral (medium effect), negative-positive (small effect), and positive-neutral within comparisons (medium effect). Negative stimuli elicited higher P3 and LPP amplitudes in this group, as well as positive stimuli. In low-anxious populations, significant overall effects were found for the negative-neutral (medium effect) and negative-positive contrasts (small effect) with no significant effects being reported for the positive-neutral contrast. Following previous studies, such results suggest that both arousal and emotional valence of stimuli modulates P3 and LPP amplitudes (e.g., Hajcak et al., 2010; McGhie et al., 2021).

Regarding valence, the negative-positive contrast was significant for both anxious and low-anxious individuals (i.e., higher P3 and LPP amplitudes in negative stimuli vs. positive stimuli). This is consistent with the idea that during human evolution the brain was shaped to be mainly oriented to danger cues as an adaptive mechanism for survival (Azriel & Bar-Haim, 2020). Still, effects were overall larger for emotional stimuli, revealing higher P3 and LPP amplitudes for emotional arousing content and, consequently, a stronger attentional bias to positive and negative stimuli across samples (Sass et al., 2010). More specifically, effects were significant for the positive-neutral stimuli in anxiety, which strengthens the emotionality hypothesis – arguing for overall increased emotional processing in anxiety (Martin et al., 1991).

Nonetheless, the negative-neutral and negative-positive effects were quantified as being higher in magnitude in the anxious group than in the low-anxious group, revealing that attentional bias towards negative stimuli is exacerbated in such samples. This is in line with studies stressing how anxious individuals seem to be highly sensitive to perceived (and not necessarily real) threatening stimuli (e.g., Azriel & Bar-Haim, 2020; Bar-Haim et al., 2007; Clauss et al., 2022; Zhang et al., 2017).

4.1.2. Between-subjects analysis

Despite the previous findings, P3 and LPP amplitudes did not differ across anxious groups and controls. The overall effect was non-significant for the neutral, positive, or negative conditions between groups, which contradicts our main hypothesis. However, when considering negative stimuli and their subcategories, a small to medium positive effect was found for the disorder-relevant stimuli, reflecting higher P3 and LPP amplitudes in anxious individuals. In other words, anxious individuals seem to allocate more attention and neuronal resources for processing a negative stimulus when there is relevant threat information triggering their own fear. This provides direct evidence that P3 and LPP modulation are one of the mechanisms that underlie the attentional bias toward threat, with the effect being specific to anxiety.

Our results converge directly with a previous meta-analysis from Pergamin-Hight and colleagues (2015) who reported that attentional bias toward threat in anxiety-related disorders seems to be mostly observed during the presentation of disorder-congruent threatening stimuli. Thus, our findings support that attentional resources are particularly directed to threat information triggering individuals' fears, unraveling the importance of personally relevant threat information in anxiety manifestations. That is, when stimulus' content is specific to the individual's disorder or symptoms, it elicits a stronger bias (e.g., Trotta et al., 2021; Yiend et al., 2018).

It also supports the role of schema-driven processing threat-bias in anxiety; i.e., how threat-biased mental structures guide and influence the way individuals read and provide meaning to the environment, leading to the recurrent and systematic perception that the world is overly unsafe (e.g., Azriel & Bar-Haim, 2020; Bar-Haim et al., 2007; Beck & Clark, 1997; Mogg & Bradley, 1998). Top-down regulation of attention may be compromised in anxiety (Cisler & Koster, 2010; Shi et al., 2019), given that orienting automatic response systems can overcome motivated, voluntary allocation of attention (e.g., Blair et al., 2007; Corbetta & Shulman, 2002; Coombes et al., 2009). According to Beck and Haigh (2014), once the individual is hypervigilant to cues that confirm one's fears and expectations, selective inputs will arrive at information-processing systems, compromising adaptive functioning and contributing to the maintenance of anxiety.

4.2. Moderators

Age did not moderate the results, while gender did. P3 and LPP amplitudes were particularly increased in studies including more females in the final sample, suggesting that gender may account for differences in attentional bias toward threat, with females being more sensitive to threat stimuli than males (Goos & Silverman, 2002; McClure, 2000). This is of high importance, considering females might show a high prevalence of anxiety-related disorders than males (Tan et al., 2011; Zhao et al., 2014; Zhang et al., 2017; but see also Kinney et al., 2017). However, this result should be interpreted with caution since it was not found systematically across analyses.

The absence of moderation effects regarding the ERP type (P3 and LPP), in both between- and within-subjects analyses, suggests that P3 and LPP are related ERP components, with little to no variability regarding the results from studies measuring P3 or LPP amplitudes. Thus, both ERPs seem to capture attentional bias toward threat, possibly translating evolutionary processes for processing danger cues (Haselton et al., 2016; Schupp et al., 2004; 2006).

The type of sample moderated the between-subjects analysis' findings, revealing a small positive effect (i.e. higher P3 and LPP amplitudes for negative stimuli) for community-dwelling samples without a prior formal diagnosis. It can be theorized that community and subclinical samples are more likely to be treatment-naïve – not subject to pharmacological or psychological interventions – which might impact the degree of attentional bias toward threat and ERP modulations. That being the case, medication and psychological interventions (e.g., Attention Bias Modification Treatment; Eye Movement Desensitization and Reprocessing Therapy; Cognitive Behavioral Therapy) may have attenuated attentional bias shown by anxious individuals (Bandelow et al., 2015; Khoury-Malhame et al., 2011; Mogg & Bradley, 2018). In fact, effects were larger for medication-free samples than for medicated samples, meaning that pharmacological interventions could diminish the anxiety symptoms and attentional bias to threatening stimuli. This hypothesis is supported by studies demonstrating that anxiety medication is effective in reducing anxiety symptoms (Bandelow et al., 2015). Since attentional bias toward threat is thought to be a core mechanism of anxiety, it might be eased by pharmacological and psychological interventions. Nonetheless, within-analysis effects were similar across clinical and subclinical samples. Taking both results together, attentional bias to threatening stimuli can be observed in both samples, probably being normally distributed in the general population.

The absence of comorbidities also moderated both the between- and within-subjects analyses' findings. It remains plausible that comorbidities mitigate the attentional bias specific effect in anxiety, which strengthens the above arguments and the idea that it can be a specific mechanism of anxiety. For example, in depression, which is highly comorbid with anxiety disorders (Groen et al., 2020), no attentional bias has been reported (for a review see Rogers, 2020).

Regarding task type, in both between- and within-subjects analyses, Free Viewing Tasks elicited higher P3 and LPP amplitudes. The within-subjects analysis also revealed that the Emotional Stroop Task and the Oddball Paradigm also elicited higher P3 and LPP amplitudes. This may suggest that, when a task does not recruit substantial cognitive resources other than processing the stimulus, subjects can pay undivided attention to it, focusing more on the emotional valence of the stimulus.

Regarding electrode sites, significant results were distributed across several topographical regions (i.e., all electrode sites seem to elicit significant effects). Yet, parietal regions were the most consistent ones (Harrewijn et al., 2017; Luck & Kappenman, 2011; Polich, 2007). Mean amplitudes measures elicited higher P3 and LPP amplitudes which suggests that this measure is more reliable than maximum peak amplitudes, consistently with recent guidelines in ERPs methodology (Luck, 2014).

Finally, the Fear dimension of the HiTOP Internalizing Spectrum emerged as a more systematic moderator of large positive effects on P3 and LPP amplitudes in negative stimuli. This result reveals that individuals with fear-related disorders – as framed by the HiTOP model - show higher attentional bias towards negative information, as measured by P3 and LPP brain correlates. More specifically, Specific Phobias and Social Anxiety Disorder seem to account for this result in the between-groups analysis. A large effect was also reported in Specific Phobia for the negative-neutral comparison. Yet, Fear and Distress were both significant moderators in the negative-positive comparison. Within-subjects analyses further showed that Post-Traumatic Stress and Obsessive-Compulsive Disorder, clustered within the Distress dimension of HiTOP Internalizing Spectrum were significant moderators. However, the magnitude of the effects was smaller. Therefore, the attentional bias toward threat might not be a systematic biomarker across all anxiety dimensions (Garland & Howard, 2014), but rather a more specific transdiagnostic biomarker of the HiTOP Fear spectra.

4.3. Limitations, recommendations, and future directions

The current study has some limitations that should be acknowledged. First, even though the literature search was exhaustive, and no publication bias was found, some unpublished studies or non-included in online databases may have been missed. Second, the studies included in this review varied significantly in the P3 and LPP time windows, which in turn may jeopardize the functional interpretation of these ERPs. Due to this inconsistency in literature, we could not impose any criteria regarding time-windows and topography, further contributing to the reported studies heterogeneity. A common criterion is needed in future studies to analyze the time windows of these brain potentials, to reach a satisfactory homogeneity across the field. Third, the majority of samples only included adults, restraining the interpretation of our results to young and older adults. Moreover, most studies did not disclose the sample's age range. Future studies should address this gap, namely by conducting longitudinal studies across distinct developmental stages. This would provide interesting inputs into how we conceptualize attentional bias toward threat in anxiety-related disorders. Fourth, the data loss was excessive, mainly due to flaws in studies' anxiety assessment and attentional bias paradigms, which led to their exclusion. Fifth, the number of effects per stimuli category was uneven, with more effects being included in the negative category. Thus, non-significant findings in other categories could be due to a lack of computed effects.

Lastly, anxiety conceptualization has changed in recent years, and so have the diagnostic criteria for anxiety disorders (Stein, 2014). This might have influenced the threshold of the number and severity of symptoms needed to be included in the clinical samples, given that most research uses these criteria to select participants. For instance, a between-group design was used to code clinical/subclinical and control groups. This classification of included samples might not be in agreement with how anxiety is currently conceptualized: a spectrum of symptoms with a normal distribution across the population, in which levels of severity vary (Kotov et al., 2017). Therefore, future studies should conduct correlational analysis, to reliability estimate the full range continuum of the anxiety spectrum and its associations with ERP measures.

5. Conclusion

The current meta-analyses examined attentional-threat bias mechanisms across the anxiety spectrum at the brain level. Our findings suggest that the emotional valence of the stimuli modulates the P3 and LPP amplitudes, in anxious and low-anxious samples. Even so, anxious individuals seem to allocate more attentional resources towards disorder-congruent negative stimuli (i.e., this effect does not seem to extend to negative stimuli in general). The Fear dimension of the HiTOP Internalizing further accounted for these results, revealing that attentional bias toward threat may be a transdiagnostic mechanism linking disorders clustered in the HiTOP Internalizing-Fear spectra (vs. Internalizing-Distress spectra where the results were more inconsistent). These results can be of great importance for the treatment of anxiety disorders included in the Fear dimension insofar Attention Bias Modification treatments targeting relevant-threatening stimuli may be especially effective in fear-related disorders. Since attentional bias, fear, and anxiety have a bidirectional relationship, it is plausible to expect that intervening on the first will ameliorate the symptoms of anxiety (Van Bockstaele et al., 2014).

Upcoming empirical research should attempt to replicate these findings by exploring the attentional bias towards relevant threats, in comparison to non-relevant threat, while controlling the shared variance between anxiety subdimensions included in the Fear and Distress dimensions of the HiTOP Internalizing Spectrum. This would highlight transdiagnostic or specific biomarkers across these disorders.

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Declarations of interest

None.

Data availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.biopsycho.2022.108475.

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