

## REGISTERED REPORT

# Expectancy and attention bias to spiders: Dissecting anticipation and allocation processes using ERPs

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## Abstract

The current registered report focused on the temporal dynamics of the relationship between expectancy and attention toward threat, to better understand the mechanisms underlying the prioritization of threat detection over expectancy. In the current event-related potentials experiment, a-priori expectancy was manipulated, and attention bias was measured, using a well-validated paradigm. A visual search array was presented, with one of two targets: spiders (threatening) or birds (neutral). A verbal cue stating the likelihood of encountering a target preceded the array, creating congruent and incongruent trials. Following cue presentation, preparatory processes were examined using the contingent negative variation (CNV) component. Following target presentation, two components were measured: early posterior negativity (EPN) and late positive potential (LPP), reflecting early and late stages of natural selective attention toward emotional stimuli, respectively. Behaviorally, spiders were found faster than birds, and congruency effects emerged for both targets. For the CNV, a non-significant trend of more negative amplitudes following spider cues emerged. As expected, EPN and LPP amplitudes were larger for spider targets compared to bird targets. Data-driven, exploratory, topographical analyses revealed different patterns of activation for bird cues compared to spider cues. Furthermore, 400–500 ms post-target, a congruency effect was revealed only for bird targets. Together, these results demonstrate that while expectancy for spider appearance is evident in differential neural preparation, the actual appearance of spider target overrides this expectancy effect and only in later stages of processing does the cueing effect come again into play.

## KEYWORDS

attention bias in spider fear, CNV, EPN, ERP, expectancy bias in spider fear, LPP

## 1 | INTRODUCTION

Several cognitive biases are associated with anxiety in general and with spider phobia in particular. One of these biases is *attention bias*, which is exhibited through three

components. The first two are marked by faster engagement with feared stimuli than with neutral stimuli, and slower disengagement from feared stimuli than from neutral ones. These two components are followed by avoidance of fearful stimuli among fearful participants (for reviews,

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see Abado, Richter, et al., 2020; Cisler & Koster, 2010). Attention bias is a key feature of spider phobia and has been widely researched (e.g., Flykt & Caldara, 2006; Öhman et al., 2001). Indeed, research shows that fear may contribute to the direction and magnitude of attention bias, which in turn contributes to the maintenance of fear, creating a vicious cycle that maintains fear, anxiety and attention bias (for a review, see Van Bockstaele et al., 2014). These findings are especially important in the therapeutic context, as reduction of attention bias can also lead to a reduction in phobia symptoms. Such desired reduction can be accomplished using specifically developed attention bias modification (ABM) methods (for more information on ABM, see McNally, 2019; Shechner et al., 2012).

A priori expectancies, which can also be biased, constitute one important factor that affects attention bias. In the case of spider phobia, *encounter bias* (Aue & Høeppli, 2012) occurs when spider-fearful individuals overestimate the likelihood of encountering a spider compared to non-fearful individuals (for a review on the expectancy bias toward positive stimuli, see Dricu et al., 2020; for a review on the expectancy bias toward negative stimuli, see Aue & Okon-Singer, 2015; de Jong & Daniels, 2020). *Consequence bias* is another type of expectancy bias in which participants overestimate the negative consequences that will follow their encounter with the fear-relevant stimulus (Aue & Høeppli, 2012).

While attention bias itself has been studied extensively, only a few studies have examined how a priori expectancies affect attention bias. Some of these studies specifically examined the interaction between a priori expectancies and attention bias in individuals with spider phobia (Aue et al., 2013, 2016, 2019). Expectancies were manipulated using a verbal cue indicating the likelihood that a certain target stimulus would appear in a subsequent visual search array. There were three types of cues: a spider cue (“spider 90%”), a bird cue (“bird 90%”) and an ambiguous cue (“spider bird 50%”/“bird spider 50%”). Following the cue, participants were shown a visual search array comprising nine pictures: eight pictures of neutral distractors (butterflies) and one deviant picture (a target)—either a threatening picture (spider) or a neutral one (bird), which in turn was either congruent or incongruent with the cue. Participants were asked to discriminate between the targets (spider or bird) as quickly and as accurately as possible. As expected, participants with spider phobia, in particular, exhibited a general attention bias (i.e., faster reaction times (RTs)) toward spider targets compared to bird targets. Nevertheless, an interaction between cue and target was found in both groups of participants, such that while the preceding cues had a beneficial effect on bird detection, spider detection was quick and unaffected by cueing (Aue et al., 2013). In other words, RTs were the

shortest for both congruent and incongruent spider target trials, slower for congruent bird target trials, and the slowest for incongruent bird target trials. These behavioral results have been replicated in an autonomic measures study (Aue et al., 2016), as well as in a functional magnetic resonance imaging (fMRI) study (Aue et al., 2019). Thus, it seems that due to its threatening value, the appearance of a spider target might override the control of endogenous attention driven by the cue (i.e., the expectancy effect).

To summarize, several studies have used behavioral, autonomic, and neural measures to examine the interaction between expectancies and attention bias toward spiders (Aue et al., 2013, 2016, 2019). Results suggest that there is a competition between endogenous processes which are elicited by a-priori probabilities and exogenous processes induced by the threatening value of spiders. However, the exact temporal dynamics of the neurocognitive mechanisms underlying the competition between expectancy and orienting of attention toward spiders have not been studied yet. To fill this gap, we harnessed electroencephalography (EEG) in unselected adult participants and extracted specific event-related potential (ERP) components that inform about expectancy versus attention allocation during the processing of threat-related stimuli. Understanding the nature of this interaction can help in developing treatments aimed at reducing attention bias, thereby reducing phobia and anxiety symptoms. This line of inquiry is also theoretically relevant, as it is more ecological and informative to study cognitive biases together rather than separately (for more details on the combined cognitive bias hypothesis, see Aue & Okon-Singer, 2015; Everaert & Koster, 2020).

## 1.1 | The current study

The current experiment sought to explore the electrophysiological time-course of threat processing when effects of expectancy versus exogenous attention allocation were carefully considered together as well as disentangled from each other. To this end, the current study focused on three successive ERP components: first, the contingent negative variation (CNV), which reflects anticipation and preparatory processes. Examining the CNV allowed us to contrast spider cues with bird cues. Moreover, we also examined two ERP components that reflect early and late emotional processing following target onset: the early posterior negativity (EPN) and the late positive potential (LPP), respectively. Both EPN and LPP have been found to reflect “natural selective attention” at different processing stages that are sensitive to evolutionary significant information, such as spiders, snakes, and content involving threat and mutilation (for reviews, see Olofsson et al., 2008, Schupp et al., 2006; see also Schupp & Kirmse, 2021). Accordingly,

these three components allowed us to cover a broad window, spanning from cue presentation to target processing, thereby disentangling the contribution of expectancy (CNV) from actual threat processing (EPN and LPP).

### 1.1.1 | Contingent negative variation

The CNV is a slow negative-going wave that appears between a warning stimulus (S1) and an imperative stimulus (S2). The CNV is mostly elicited following cues, and when there is a constant interval of several seconds between S1 and S2 (for a review, see Brunia, van Boxtel, et al., 2011). The CNV is believed to reflect anticipatory attention and orienting of attention. In an emotional context, Amrhein et al. (2005) studied consequence bias in participants with panic disorder and in healthy control participants. Panic-relevant (emergencies), phobia-relevant (spiders) and neutral (mushrooms) pictures were randomly paired with an aversive outcome (startle sound). During the CNV interval (4000–6000 ms post-picture onset), an interaction was found between participant group and picture category. Specifically, the CNV of participants with panic disorder was significantly more negative for emergency than for spider pictures, while in control participants, the CNV for spider pictures and for emergency pictures was significantly more negative than for mushroom pictures. Thus, control participants exhibited larger CNV amplitudes toward panic-relevant and phobia-relevant cues, compared to neutral cues.

Other studies also found that the CNV was sensitive to threat cues. For instance, Regan and Howard (1995) used a tone-slide paradigm (i.e., acquisition and extinction), in which the tone predicted an upcoming white noise after a fear-relevant (small animals)/-irrelevant (landscapes) slide. CNV amplitudes were measured throughout the entire trial (8 s). In the fear-relevant condition, CNV amplitudes were significantly larger toward trials that predicted the white noise, compared to trials that did not include a white noise, both during acquisition and extinction sessions. In the fear-irrelevant condition, the differentiation between both trial types was weaker in both sessions. Thus, overall, the CNV was sensitive to threat cues, even during extinction, in the fear-relevant condition, but not in the fear-irrelevant condition. Using the CNV, the current study examined the time course of differential expectancy and anticipatory effects for threatening cues versus neutral cues.

### 1.1.2 | Early posterior negativity

The EPN is an early occipito-temporal component that reaches its maximum amplitude ~200–300 ms after

stimulus onset. The EPN is believed to reflect early enhanced attention in emotional contexts, especially toward evolutionary-relevant stimuli (for reviews, see Olofsson et al., 2008; Schupp et al., 2006). The EPN has also been studied using priming/expectancy and attention paradigms. For instance, Hietanen and Astikainen (2013) showed participants positive and negative scenes (primes), followed by happy, sad, and neutral facial expressions (targets). Trials were congruent or incongruent in terms of valence. They found that the EPN was sensitive to negative primes and targets. However, EPN was more sensitive to happy faces that were preceded by negative primes compared to positive primes, while sad faces were not affected by primes, resulting in a significant interaction between prime and target (Hietanen & Astikainen, 2013).

Additionally, Flaisch et al. (2008) showed participants a continuous stream of pleasant, unpleasant and neutral pictures. Each picture was preceded by a prime picture of the same category. A priming effect of emotional stimuli was found, regardless of congruency. In other words, as long as the prime was not neutral (i.e., either pleasant or unpleasant), *smaller* EPN amplitudes were found toward the subsequent picture, regardless of its valence. Using the EPN, the current study examined early emotional processing and attention bias toward threatening compared to neutral stimuli.

### 1.1.3 | Late positive potential

The LPP reflects elaborated processing in emotional contexts, especially toward evolutionary-relevant stimuli (for reviews, see Olofsson et al., 2008; Schupp et al., 2006). While the EPN reflects natural selective attention during early processing stages, the LPP is similarly sensitive to evolutionary-significant stimuli but likely reflects additional later processing stages. However, findings regarding the LPP are mixed. Flykt and Caldara (2006) used a visual search task similar to the one used in this experiment in order to measure LPP amplitudes toward fear-relevant and fear-irrelevant stimuli in participants with either spider or snake phobia. Participants with spider phobia exhibited larger LPP amplitudes toward spider targets than snake and neutral targets. Similarly, participants with snake phobia exhibited larger LPP amplitudes to snake targets than spider and neutral targets, while control participants did not exhibit prioritized processing toward any kind of target.

A recent study used a paradigm that is very similar to the one used here in terms of cue validity (Johnen & Harrison, 2019). This study used symbolic cues that predicted the valence of the upcoming picture on 70% of the trials. Results showed that the LPP component was

sensitive to validity and to valence but not to the interaction between these two factors. Other cueing studies revealed that the LPP is sensitive to predictability (Lin et al., 2012, 2018) as well as to trait intolerance of uncertainty (Gole et al., 2012). Using the LPP, the current study examined late emotional processing and attention bias toward congruent and incongruent trials with threatening and neutral pictures.

To summarize, mixed findings exist regarding the effects of cue congruency and valence on EPN and LPP amplitudes to neutral and emotional targets. These differences may be related to specific tasks, paradigms, designs, and requirements. As our task differs to some extent from all of the aforementioned tasks, it could shed light on the interaction between expectancy and attention toward evolutionary-relevant stimuli when the cues are not 100% predictive and when a visual search array is presented.

#### 1.1.4 | Hypotheses

In our previous studies based on a similar visual search task, results showed a consistent and robust attention bias toward spiders in both participants with spider phobia and control participants with low fear of spiders. Behaviorally, we expected participants to detect spider targets quicker than bird targets. Moreover, an interaction between cues and targets was also hypothesized, whereby participants were expected to react faster on congruent compared to incongruent trials, yet this effect should interact with target type: a larger congruency effect was expected for bird targets than spider targets, given that we previously found across several studies that the appearance of spider targets could override expectancy driven by the cue (e.g., Aue et al., 2013, 2016, 2019).

Importantly, as shown in the literary overview, previous ERP studies have employed various paradigms and often found contradictory results. Thus, our ERP hypotheses were mostly based on our own previous studies (Aue et al., 2013, 2016, 2019), which have used a similar paradigm. When hypotheses could not be made based on our own previous studies, we have referred to the relevant literature. For instance, we refer to Regan and Howard's study (Regan & Howard, 1995) for the CNV hypothesis. While this study used a very different paradigm, which included acquisition and extinction, it did include several aspects which are very similar to our own study: (1) small animals served as fear-relevant stimuli; (2) participants were unselected; and (3) CNV was measured following threatening and neutral cues.

For the CNV component, we hypothesized larger amplitudes for spider cues than bird cues. This hypothesis

is in line with Regan and Howard's study (1995), which showed that the CNV was sensitive to threat cues in fear-relevant conditions (i.e., pictures of small animals), among a sample of unselected participants (see also Amrhein et al., 2005, for similar results). For the EPN, we expected a main effect of target. Specifically, we expected larger amplitudes for spider targets compared to bird targets, regardless of the preceding cue. This hypothesis is in line with the study by Flaisch et al. (2007), which found that the EPN was sensitive to emotional stimuli, regardless of their congruency with the preceding prime. For the LPP, we expected an interaction effect between cues and targets: the LPP was expected to be larger for congruent than incongruent trials, with this congruency effect being larger for bird trials than spider trials. This hypothesis is in line with previous studies which have found that the LPP is larger for congruent/certain trials compared to incongruent/uncertain trials (Lin et al., 2012, 2018), and our own studies, which behaviorally, physiologically, and neurally showed larger congruency effects for bird targets compared to spider targets (Aue et al., 2013, 2016, 2019).

To summarize, we hypothesized that a differential expectancy effect could be created by spiders at the cue level (CNV), but these threat-related stimuli could nevertheless benefit from enhanced processing at the target level irrespective of expectancy, especially at an early stage of target processing (during the EPN), thereby reflecting a genuine early attention bias toward them. In this framework, target processing could be facilitated by expectancy at a later stage of processing, as reflected by the LPP. This hypothesis is also in line with our previous studies, which employed intracranial ERP methods and found that early processing of fearful stimuli was characterized by emotional effects which were independent of direction of attention, while later processing was characterized by a modulation of the emotional response by attention (Pourtois et al., 2010).

## 2 | METHODS

### 2.1 | Participants

The sample size was determined using G\*Power (version 3.1.9.7; Faul et al., 2009). Our previous studies using the same paradigm have found large effect sizes for the cue-target interaction:  $\eta^2_p = .44$  (Aue et al., 2013),  $\eta^2_p = .2$  (Aue et al., 2016) and  $\eta^2_p = .31$  (Aue et al., 2019). Accordingly, in the current study, we used a large effect size, which is the smallest of our previous studies ( $\eta^2_p = .20$ ; a large effect size is defined as an effect size that is  $\eta^2_p > .14$ ; Cohen, 2013) to estimate the sample size. Specifically,  $\eta^2_p$  expresses the sum of squares of the effect in relation to the sum of squares of the effect



and the sum of squares of the error associated with the effect. As we used the  $\eta^2_p$  that is generated by SPSS, it already incorporated the correlation between paired measures (Lakens, 2013).

Accordingly, 30 participants were needed to reach a power of .95 with an error probability of .02 and four repeated measures (2 cues  $\times$  2 targets), using the “as in SPSS” setting. We recruited 36 participants in total, taking into account exclusion of participants due to post-experimental exclusion criteria (see below). Participants completed the study in exchange for course credit or payment, as instructed by the ethics committee. This study was approved by the ethics committee of the School of Psychological Sciences at the University of Haifa (Approval #070/20).

Exclusion criteria included history of attention deficit hyperactivity disorder, psychiatric and/or neurological history and current use of psychiatric medications. Participants were prescreened for these criteria using a screening questionnaire. Post-experimental exclusion criteria included: (1) Extreme accuracy rates or RTs ( $\pm 3$  standard deviations [*SDs*] above/below the mean [*M*]) as calculated for each participant in comparison with the entire sample. The same criterion was applied to individual trials per participant per condition. (2) Excessive noise in the raw electroencephalography (EEG) data. Inclusion criteria were normal or corrected-to-normal vision and right dominant hand.

Of the 36 recruited participants, six participants were excluded from the final analysis: one due to extremely low accuracy rates (55%, which was more than 3 *SDs* below the mean), one due to technical issues (electrodes PO3 and PO4, which are 2 out of the 5 electrodes used to measure the EPN, detached halfway through the experiment), and 4 participants had excessive noise in the raw EEG data (i.e., rejection rate that is over 25% of trials per participant, in line with the recommendation of Luck, 2014). The criteria for artifact rejection are presented below, in the “Data Processing” section. Thus, the final sample included 30 participants (6 males;  $M_{\text{age}} = 23.73 \pm 3.11$ ). Less than 1% of the trials were excluded due to extremely fast or slow RT.

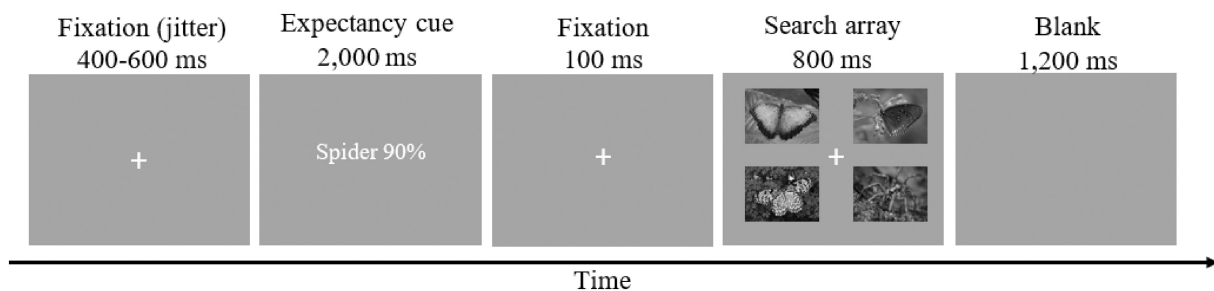
## 2.2 | Stimuli

This study used the exact same stimuli as our previous studies (Aue et al., 2013, 2016, 2019). Specifically, 30 pictures of spiders, 30 pictures of birds and 100 neutral pictures of butterflies were used, with all pictures matched for contrast, luminance and spatial frequency using MATLAB (MathWorks; version R2017a).

## 2.3 | Procedure

Compared to our previous studies that focused on peripheral physiological effects or fMRI, the paradigm was adapted to make it compatible with an EEG study. Although in our previous studies long durations (2000–3000 ms) were used for fixation and stimulus presentation, shorter durations were used here to extract conspicuous CNV, EPN and LPP ERP components (see Figure 1). Because of the reduced presentation duration compared to our previous studies, we also reduced the number of pictures shown in the visual search array, from 9 to 4 pictures and reduced the visual search array presentation duration from 2500 to 800 ms. Expectancy cues were kept relatively long (2000 ms), in line with our previous studies and with other studies which measured the CNV over long durations, depending on the task and on trial length (for a review, see Brunia, van Boxtel, et al., 2011). Lastly, a short fixation (100 ms) between cues and targets was presented in order to make participants quickly fixate before the presentation of the targets. These parameters were chosen based on a behavioral pilot study conducted with 20 participants that showed similar results (i.e., interaction between the cue and target) as Aue et al. (2013, 2016, 2019).

Participants were first asked to fill in some questionnaires (see the Supplementary Materials for details regarding the administered questionnaires and related findings). During the experiment, participants then took part in 20 practice trials. Then, they were asked to use a visual analogue scale (VAS) ranging from 0% to 100% to rate the probability of encountering the bird and spider targets throughout the



**FIGURE 1** An example of a congruent trial: a spider cue is followed by a spider target (right column, bottom row). Pictures in the array are not to scale. Participants could still respond when the blank screen appears.

experiment (two questions presented in random order, one for each type of target). This measure reflects participants' a-priori expectancy of encountering each type of target.

After that, the experiment began and consisted of five blocks, each comprising 100 trials (500 trials overall), with a break between them. Each trial began with a fixation point (average of 500 ms, jittered between 400 and 600 ms). Then, a cue appeared for 2000 ms, indicating the probability of the target stimulus type in the next trial (spider cue: "spider 90%", bird cue: "bird 90%", ambiguous cue: "spider bird 50%" or "bird spider 50%"). Ambiguous cues served as a means to elicit a sense of ambiguity/uncertainty and to encourage participants to use the cue, which is mostly predictive. This was followed by another fixation (100 ms), followed by the search array. The array included a fixation with four pictures, two on each side: three pictures of butterflies and one deviant (target) picture of either a bird or a spider. Picture size was 480 × 270 pixels (13.5 × 7.75 cm) and each picture was located 3 cm away from the fixation point; screen size was 62 cm (24 in) and participants were seated 60 cm away from the screen. Each picture had an equal probability of appearing in any one of the four possible locations. The visual search array was shown for 800 ms and participants were instructed to determine, as quickly and as accurately as possible, the category of the target stimulus by pressing the P key for spider targets and Q key for bird targets (counterbalanced). Participants could respond during the presentation of the search array or the following blank screen (1200 ms; see [Figure 1](#) for an example of the procedure). Catch trials (additional 25 trials in the experiment +4 trials during practice) included a purple fixation rather than a black one. For this type of trials, participants were asked to press the space key as soon as possible, rather than detect the target. The aim of catch trials was to make sure that participants fixate. In reality, and in line with our previous studies, there was a 75% congruency rate between cues and targets, excluding ambiguous trials (Aue et al., 2013, 2016, 2019). This was done in order to reassure participants of the validity of the cues and to encourage them to use the cues, while still being able to collect enough incongruent trials within a reasonable timeframe. Thus, in reality, we could use 25% of trials as incongruent trials. The experimental paradigm took about 40 min to complete, with a break approximately every 8 min.

Following the experiment, participants were asked to answer several questions:

1. Using a VAS that was identical to the one used to measure a priori expectancies, participants were asked to rate the proportion of spiders and birds they encountered throughout the experiment (two questions presented in random order, one for each type of target). This measure reflects participants' a-posteriori

estimations of the appearance of each target (i.e., memory bias).

2. As a manipulation check and to make sure that spiders were indeed considered unpleasant, participants were shown 15 random pictures from the experiment (five from each category—spiders, birds and butterflies). For each picture, they were asked to indicate how pleasant and how unpleasant it was, each on a scale from 0 to 8 (Kron et al., 2013). Each picture appeared for 4 s, followed by the two scales.

## 2.4 | Design

The study employed a 2 × 2 within-subject design, with the following factors: *cue* (bird, spider) and *target* (bird, spider). Trials with ambiguous cues were not analyzed as they only constituted 12% of trials, in line with our previous studies, which have used similar proportions (Aue et al., 2013, 2016, 2019). In other words, the main comparison for expectancies was spider cues (threat cues) versus bird cues (neutral cues). Thus, overall, there were two congruent conditions (bird cue followed by a bird target; spider cue followed by a spider target) and two incongruent conditions (spider cue followed by a bird target; bird cue followed by a spider target).

## 2.5 | Data processing and analysis

The current study was preregistered, and all relevant materials, data, and analyses codes can be found online (<https://osf.io/64nzq/>).

### 2.5.1 | Behavioral recording

RT was recorded using E-Prime 3.0 (Psychology Software Tools, Pittsburgh, PA, USA).

### 2.5.2 | Behavioral analysis

RTs were analyzed with IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, NY, USA). Only correct trials were analyzed. Our variables of interest were all within-subject and included *cue* (bird, spider) and *target* (bird, spider). These variables were entered into a repeated-measures analysis of variance (ANOVA). For analyzing the interaction effects between cue and target, additional paired sample *t*-tests were conducted to measure the existence of the congruency effects separately for each type of target (bird cue-spider target vs. bird cue-bird target; bird

cue-spider target vs. spider cue-spider target). Cohen's  $d$  for paired samples was calculated for each  $t$ -test.

### 2.5.3 | EEG recording

EEG was recorded from 32 scalp sites using active, gel-based Ag/AgCl electrodes mounted in an elastic cap (Biosemi™, <http://www.biosemi.com/headcap.htm>) based on the extended 10–20 system. Continuous EEG was recorded during the task and sampled at 512 Hz using a BioSemi ActiveTwo system, with Common Mode Sense (CMS) active electrode and Driven Right Leg (DLR) passive electrode serving as ground for internal gain scaling ([www.biosemi.com](http://www.biosemi.com)).

### 2.5.4 | Data preprocessing

The data were analyzed using EEGLab (version 2021.0; Delorme & Makeig, 2004) and ERPLab plugin (Lopez-Calderon & Luck, 2014) running on MATLAB (MathWorks; version R2017a) routines. Raw EEG data was rereferenced offline to the digital average of the 32 EEG electrodes. EEG deflections resulting from eye blinks were corrected using independent component analysis (ICA). Any remaining artifacts that exceeded  $\pm 100 \mu\text{V}$  in amplitude were rejected.

### 2.5.5 | ERP analysis

ERPs were determined by averaging the 2000 ms segmented trials for cues and for targets, resulting in two cue conditions (spider cue, bird cue) and four target conditions (bird cue-spider target, bird cue-bird target, spider cue-bird target, spider cue-spider target). Offline, a 0.01 Hz high-pass filter and a notch filter were applied before pre-processing and a 30 Hz low-pass filter was applied after pre-processing. Baseline correction was set to 200 ms before stimulus onset. Only correct trials were analyzed. CNV amplitudes were scored as the mean amplitude in the interval between 1500 and 2000 ms after cue onset until stimulus onset, on frontal, central and parietal sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4; see Amrhein et al., 2005; Carretie, 2004; Mühlberger et al., 2006). A paired samples  $t$ -test was conducted to compare bird cues and spider cues. EPN amplitudes were scored as the mean amplitude in the time interval between 250 and 350 ms after array onset on occipito-parietal and occipital sites O1, O2, PO7, PO8, and Oz (Beligiannis & Van Strien, 2020; Diéguez-Risco et al., 2015; Grassini et al., 2019; Hermann et al., 2007; Hietanen & Astikainen, 2013; Langeslag & van Strien, 2018). The EPN was analyzed using an ANOVA identical to the one used for behavioral

analyses (two cues: bird vs. spider; two targets: bird vs. spider). The same paired samples  $t$ -tests were also used. LPP amplitudes were scored as the mean amplitude in the time interval from 400 to 700 ms following array onset on frontal, central and parietal sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4; Breton et al., 2014; Cuthbert et al., 2000; Langeslag et al., 2007; White & Grant, 2017). The LPP was analyzed in the same way as the EPN. Cohen's  $d$  for paired samples was calculated for each  $t$ -test.

### 2.5.6 | Bayesian analyses

For behavioral as well as ERP data: Bayesian statistical analyses were conducted using the software JASP (version 0.17.1.0; Wagenmakers et al., 2018). The Bayes factor (BF) is used for comparing two competing hypotheses (the null hypothesis, i.e.,  $H_0$  vs. the alternative one, i.e.,  $H_1$ ), as it quantifies the relative strength of evidence provided by the data for one hypothesis compared to the other one.  $\text{BF}_{10}$  indicates the Bayes factor in favor of  $H_1$  over  $H_0$ . A  $\text{BF}_{10}$  greater than 1 suggests stronger evidence for  $H_1$  than  $H_0$ , while a value less than 1 indicates stronger evidence for  $H_0$  than  $H_1$  (Quintana & Williams, 2018).  $\text{BF}_{\text{Inclusion}}$  is a different factor, used to assess the evidence for including a particular variable in a model compared to excluding it. It measures the change in the odds of the data under the inclusion model relative to the odds under the exclusion model. A  $\text{BF}_{\text{Inclusion}}$  greater than 1 indicates evidence in favor of including the variable, while a value less than 1 suggests evidence in favor of excluding it (Quintana & Williams, 2018).

## 3 | RESULTS

### 3.1 | Behavioral analysis

Participants' RTs for correct responses were analyzed. On average, errors made up 10% of all responses ( $SD = 6\%$ ). As expected, a main effect of target was found ( $F(1,29) = 53.96$ ,  $p < .001$ ,  $\eta^2_p = .650$ ;  $\text{BF}_{\text{Inc}} = 368,178.15$ ), such that participants responded faster to spider targets compared to bird targets (bird targets:  $M = 755.14$  ms; spider targets:  $M = 675.28$  ms; representing the classical effect of attention bias). A cue  $\times$  target interaction was found ( $F(1,29) = 26.07$ ,  $p < .001$ ,  $\eta^2_p = .473$ ;  $\text{BF}_{\text{Inc}} = 76,849.63$ ). Paired-samples  $t$ -tests were conducted to analyze this interaction further using two planned contrasts: (1) bird cue-spider target versus spider cue-spider target and (2) spider cue-bird target versus bird cue-bird target. As shown in Figure 2, a congruency effect was found for both spider ( $M = 21.28 \pm 30.11$  ms;  $t(29) = 3.87$ ,  $p = .001$ ; Cohen's  $d = 0.707$ ;  $\text{BF}_{10} = 54.66$ ) and bird ( $M = 31.96 \pm 40.31$  ms;  $t(29) = 4.34$ ,  $p < .001$ ; Cohen's

$d=0.793$ ;  $BF_{10}=173.247$ ) targets, as participants generally responded faster on congruent trials compared to incongruent trials for both targets.

As the current paradigm somewhat differs from our previous experiments (Aue et al., 2013, 2016, 2019), additional exploratory analyses were conducted, demonstrating that RTs in the current experiment were overall faster compared with RTs in these previous experiments (for details, see the Supplementary Materials). With regards to the questionnaires, correlations were found between the fear of spiders and intolerance of uncertainty (for details, see the Supplementary materials).

### 3.2 | ERP analysis

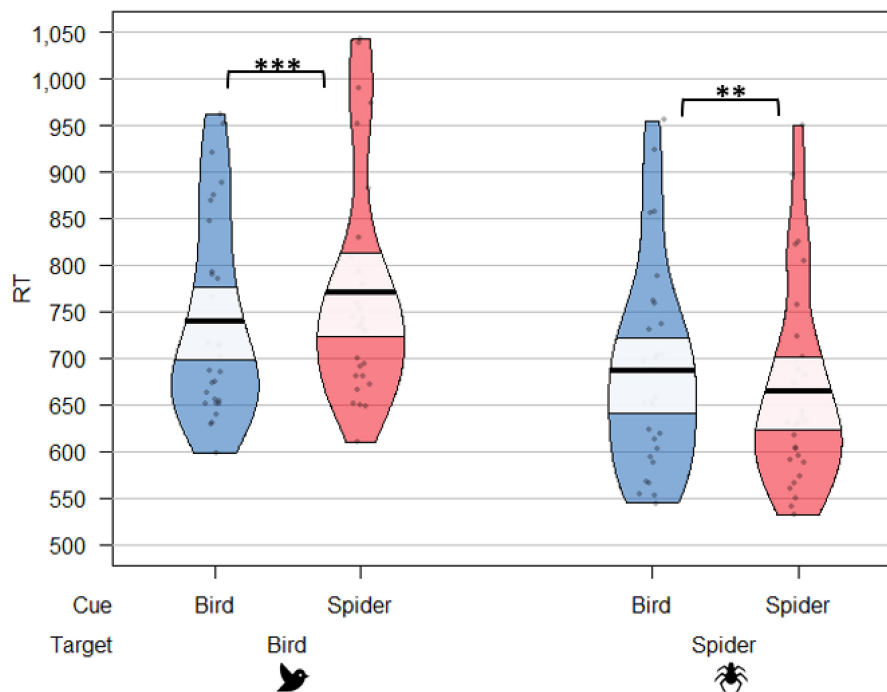
ERP analyses were conducted on correct trials, after the removal of trials which contained artifacts ( $\sim 13\% \pm 5\%$  of trials; see also Table 1).

#### 3.2.1 | Contingent negative variation

No differences in CNV amplitudes were found between bird cues ( $M=-0.284$ ,  $SD=0.428$ ) and spider cues ( $M=-0.356$ ;  $SD=0.395$ ;  $t(29)=1.105$ ;  $p=.278$ , Cohen's  $d=0.202$ ;  $BF_{10}=0.577$ ), although it was numerically larger for the latter compared to the former category. Hence, a nonsignificant trend in the expected direction was found (see Figure 3), but our hypothesis for the CNV could not be confirmed based on this (pre-registered) analysis.

#### 3.2.2 | Early posterior negativity

As hypothesized, a significant main effect of target was found, as EPN amplitudes were more negative for spider targets ( $M=6.195$ ) compared to bird targets ( $M=6.442$ ;  $F(1, 29)=4.830$ ,  $p=.036$ ,  $\eta_p^2=.143$ ;



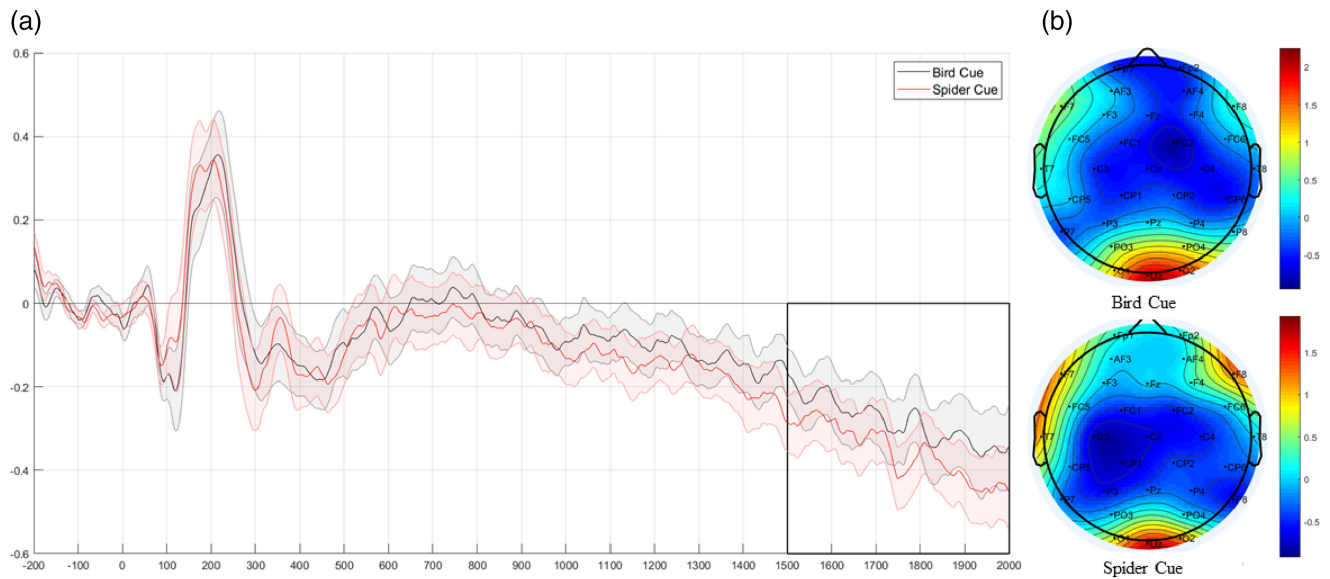
**FIGURE 2** Pirate plot of RT as a function of the cue  $\times$  target interaction. Dark horizontal lines reflect the sample mean. Horizontal bands around the sample mean reflect 95% confidence interval.  $**p < .01$ ,  $***p < .001$ . All pirate plots in the manuscript were created using R (R Core Team, 2021) and the “yarr” package.

**TABLE 1** Frequencies and the number of trials per condition.

Cue	Bird		Spider		Ambiguous	
	Bird	Spider	Bird	Spider	Bird	Spider
Number of trials	164 (131 $\pm$ 13)	56 (41 $\pm$ 6)	56 (44 $\pm$ 6)	164 (125 $\pm$ 15)	30 (24 $\pm$ 3)	30 (22 $\pm$ 3)
Frequencies	75%	25%	25%	75%	50%	50%
Total	44%		44%		12%	

*Note:* In parentheses: the mean and SD of the number of trials that was left in each condition, following the removal of incorrect responses and artifact detection (see the Section 3.5).





**FIGURE 3** (a) Grand average ERPs separately for the two cue conditions. The CNV component (cue-locked; 1500–2000 ms) is highlighted by the black rectangle. Shadows represent standard errors. The x axis represents the time axis in milliseconds (ms), spanning from 200 ms prior to cue onset until 2000 ms following it, while the y axis represents the amplitude in microvolts ( $\mu\text{V}$ ). (b) The corresponding topographical voltage map (horizontal view) for the CNV is shown for each cue condition separately. As can be seen from it, the topography of the CNV turned out to be different between these two conditions. We analyzed this topographical effect at the statistical level in an exploratory analysis (see here below).

$\text{BF}_{\text{Incl}} = 0.803$ ). Moreover and in agreement with our (pre-registered) hypothesis for the EPN, no significant interaction between cues and targets emerged ( $F(1,29) = 0.094$ ,  $p = .761$ ,  $\eta^2_p = .003$ ;  $\text{BF}_{\text{Incl}} = 0.278$ ; see Figure 4). Planned paired-samples  $t$ -tests showed that for both targets, no significant differences emerged between the two preceding cues: spider cue-bird target conditions versus bird cue-bird target conditions ( $t(1, 29) = -1.272$ ,  $p = .213$ , Cohen's  $d = -0.232$ ;  $\text{BF}_{10} = 0.404$ ) and bird cue-spider target conditions versus spider cue-spider target conditions ( $t(1, 29) = 0.597$ ,  $p = .555$ , Cohen's  $d = 0.109$ ;  $\text{BF}_{10} = 0.229$ ).<sup>1</sup>

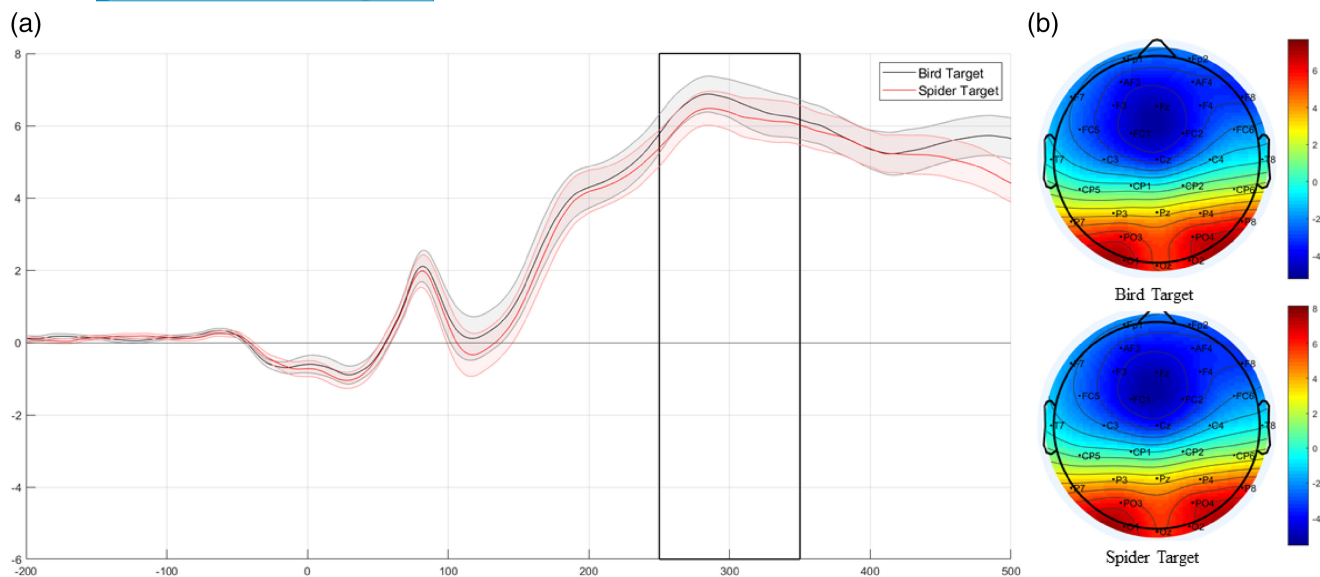
<sup>1</sup>It is important to note that since the study's design includes a larger number of congruent trials than incongruent trials, the signal-to-noise (SNR) ratio of the ERP data is smaller for incongruent trials. For this reason, we have also calculated EPN and LPP amplitudes using weighted means by condition (congruent/incongruent  $\times$  spider/bird target). The weights were applied based on the remaining trials for all participants, after the removal of noisy or incorrect trials, in line with the exclusion criteria mentioned in the Methods section (see also Table 1 for the number of trials left in each condition). With the application of weights, the results did not change, as main effects of targets once again emerged for the EPN ( $M$  of bird targets = 6.16,  $M$  of spider targets = 6.49,  $t(29) = 3.42$ ,  $p = .002$ , Cohen's  $d = 0.625$ ;  $\text{BF}_{10} = 38.26$ ) and the LPP ( $M$  of bird targets = -0.54,  $M$  of spider targets = -0.13,  $t(29) = 6.06$ ,  $p < .001$ , Cohen's  $d = 1.11$ ;  $\text{BF}_{10} = 26,700.46$ ).

### 3.2.3 | Late positive potential

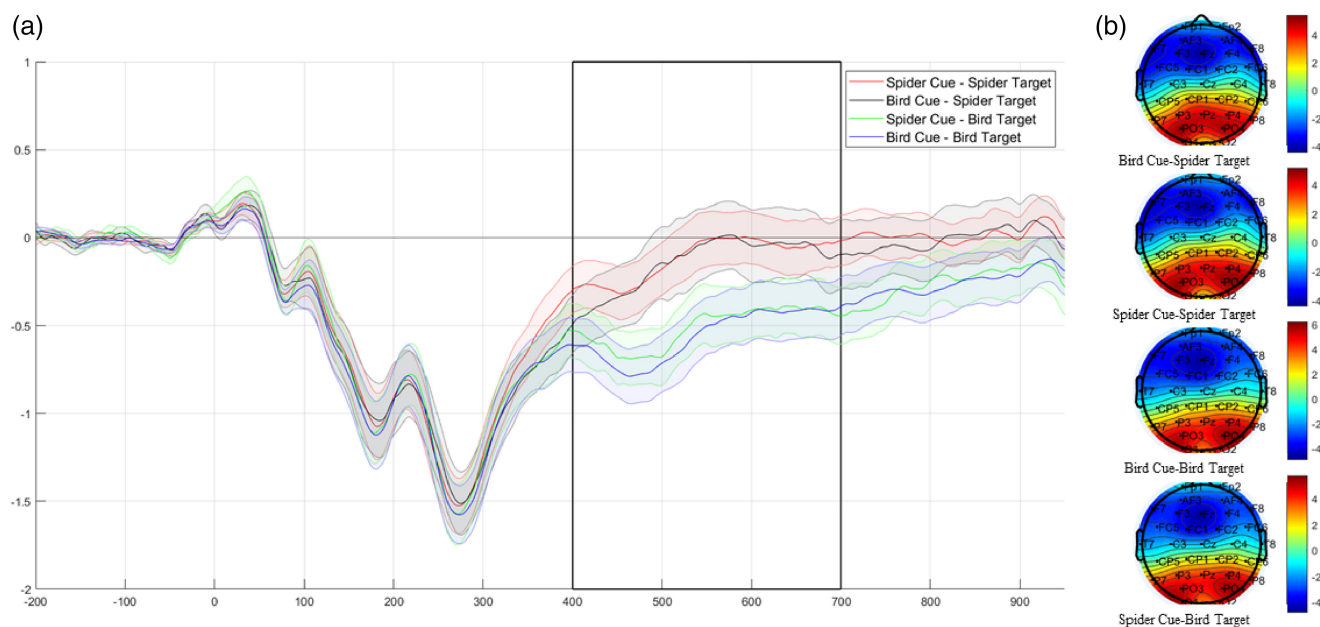
As hypothesized, a significant main effect of target was found, as LPP amplitudes were more positive for spider targets ( $M = -0.132$ ) than bird targets ( $M = -0.533$ ;  $F(1, 29) = 28.36$ ,  $p < .001$ ,  $\eta^2_p = .494$ ;  $\text{BF}_{\text{Incl}} = 2272.073$ ). However, no significant interaction between cues and targets emerged ( $F(1,29) = 0.027$ ,  $p = .870$ ,  $\eta^2_p = .001$ ;  $\text{BF}_{\text{Incl}} = 0.233$ ; see Figure 5), while such an interaction was hypothesized. Planned paired-samples  $t$ -tests showed that for both targets, no differences emerged between the two preceding cues: spider cue-bird target conditions versus bird cue-bird target conditions ( $t(1, 29) = 0.604$ ,  $p = .551$ , Cohen's  $d = 0.110$ ;  $\text{BF}_{10} = 230$ ) and bird cue-spider target conditions vs. spider cue-spider target conditions ( $t(1, 29) = -0.352$ ,  $p = .727$ , Cohen's  $d = 0.064$ ;  $\text{BF}_{10} = 206$ ).

### 3.3 | Exploratory topographical analyses

The main (i.e., preregistered) analyses were based on standard ERP component analyses and are in line with previous studies. Out of the 32 electrodes available, only 5–9 were used to score the CNV, EPN or LPP. Since expectancy and attention might also influence the



**FIGURE 4** (a) Grand average ERPs separately for the two main target conditions. The EPN component (target-locked; 250–350 ms) is highlighted by the black rectangle. Shadows represent standard errors. The x axis represents time in ms, spanning from 200 ms prior to target onset until 500 ms following it, while the y axis represents the amplitude in  $\mu\text{V}$ . (b) The corresponding topographical voltage map (horizontal view) for the EPN is shown for each target condition separately. Unlike the CNV (see Figure 3), the EPN topography turned out to be comparable for them.



**FIGURE 5** (a) Grand average ERPs separately for the four conditions (two cues  $\times$  two targets). The LPP component (target-locked; 400–700 ms) is highlighted by the black rectangle. Shadows represent the standard errors. The x axis represents time in ms, spanning from 200 ms prior to target onset until 500 ms following it, while the y axis represents the amplitude in  $\mu\text{V}$ . (b) The corresponding topographical voltage map (horizontal view) for the LPP is shown for each condition separately. As was the case for the EPN, the LPP showed a similar topography across the four conditions.

topography (i.e., electric field configuration) of these ERP components, besides their local amplitudes measured at a few electrode locations, we also performed a data-driven topographical analysis of both the cue and target-related ERP activities taking into account all electrodes and timepoints available (see Pourtois et al., 2008 for an elaboration on the advantages of this topographical analysis).

## 4 | METHODS

The dominant topographies accounting for the ERP dataset were examined using CARTOOL software (Version 4.11; developed by D. Brunet, Functional Brain Mapping Laboratory, Geneva, Switzerland). In essence, it comprises of two consecutive data analysis steps. Initially, the dominant topographical maps are extracted from the grand

average ERP data (i.e., segmentation) through a clustering algorithm that takes into account the global dissimilarity, regardless of the overall strength of the ERP signal (Lehmann & Skrandies, 1980). Subsequently, these main and dissociable topographical configurations are fitted back into the individual subject ERP data (i.e., fitting), and a quantification of their representation across conditions and participants is provided, including the global explained variance (GEV, or goodness of fit). Finally, parametric tests are carried out on the GEV to compare the different experimental conditions at the statistical level.

## 4.1 | Segmentation

To identify the dominant topographical maps, we employed K-means clustering on the entire epoch, spanning from  $-200$  ms pre-stimulus to  $2000$  ms post-stimulus onset (overall 1126 timeframes (TFs) sampled at 512Hz). The clustering method was performed with the recommended settings in CARTOOL, which included: (1) Minimum and maximum number of clusters, predefined from 1 to 10; (2) applying a smoothing kernel (Besag factor 10) of three TFs; (3) rejecting segments shorter than three TFs; (4) merging clusters if they correlated above 95%. The clustering method included 300 random trials. The best segmentation result was chosen based on both an objective meta criterion of 7 criteria previously proposed (Charrad et al., 2014).

## 4.2 | Fitting

Following segmentation, the dominant identified topographies were fitted back to the individual averages, to determine their goodness-of-fit across participants and conditions. Fitting parameters also followed the recommendations implemented in CARTOOL and included: (1) a smoothing kernel (Besag factor 10) of three TFs, and (2) rejection of segments shorter than three consecutive TFs. The main extracted measure was the GEV for each participant in each condition. The GEV was entered into paired-sample *t*-tests (for the CNV) and repeated-measures ANOVA (for the EPN and LPP), similarly to the analyses conducted in the main analysis section.

# 5 | RESULTS

## 5.1 | Segmentation and fitting, cue-locked activity

Based on the meta-criterion, a solution with nine different dominant maps was found to explain the ERP data set the best, accounting for 92.50% of the variance. During the time

window corresponding to the CNV (1500–2000 ms), two different dominant maps emerged, one for each cue. Specifically, the dominant map for bird cues was characterized by right-lateralized negativity, particularly in fronto-central areas, while the dominant map for spider cues was most negative on the left side, particularly in centro-parietal areas (see Figure 6 for segmentations and topographies). The extracted GEV, provided by the fitting of the two dominant maps in the time window of interest for the CNV (1500–2000 ms) revealed a significant interaction between cue type (spider cue, bird cue) and map ( $F(1,29)=14.062$ ,  $p=.001$ ,  $\eta_p^2=.372$ ). Paired-sample *t*-tests revealed significant differences between bird cues and spider cues for both maps ( $t(29)=-3.039$ ;  $p=.005$ , Cohen's  $d=0.555$ ;  $t(29)=2.774$ ;  $p=.010$ , Cohen's  $d=0.506$ ), as the right-lateralized map showed higher levels of explained variance for bird cues ( $M=8.9%$ ,  $SD=9.8%$ ) compared to spider cues ( $M=4.8%$ ,  $SD=8.1%$ ), while the opposite was true for the more left-lateralized map (spider cues:  $M=7.5%$ ,  $SD=9.1%$ ; bird cues:  $M=3.4%$ ,  $SD=6.2%$ ).

## 5.2 | Segmentation and fitting, target-locked activity

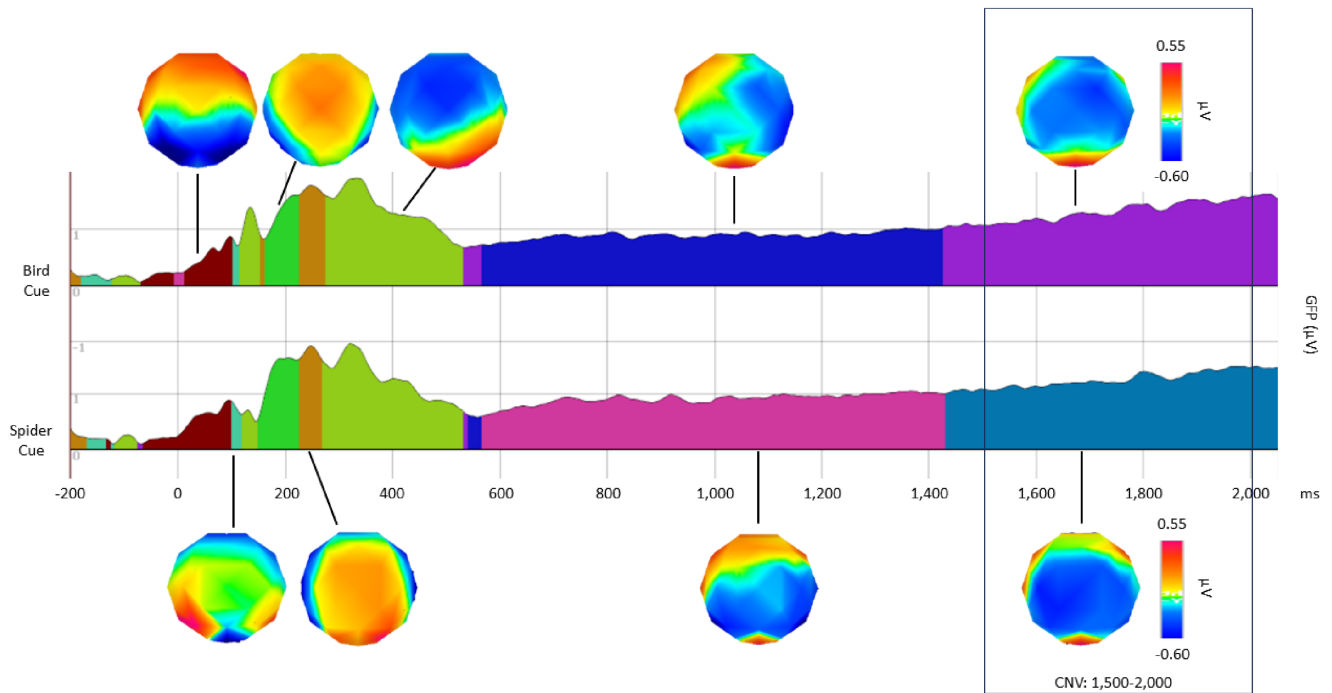
Based on the meta-criterion, a solution with seven different dominant maps was found to explain the ERP data set the best and accounted for 96.40% of the variance. During the time window corresponding to the EPN (250–350 ms) and LPP (400–700 ms), two different dominant maps emerged, one for each time-window. For each ERP component, the same topography was found for all conditions, however. Both maps are characterized by fronto-central negativity and parieto-occipital positivity, in agreement with the topographical properties of the EPN and LPP, respectively (see Figure 7 for segmentations and topographies).

### 5.2.1 | Early posterior negativity

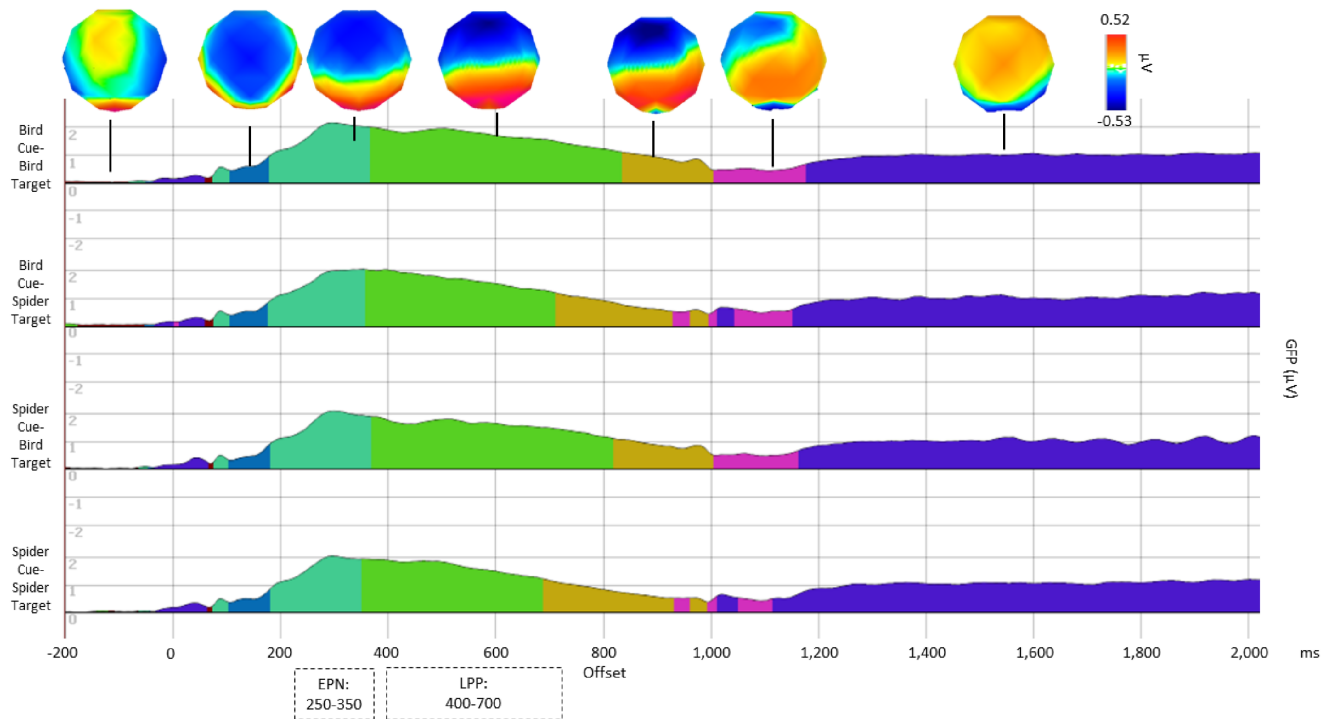
The extracted GEV, provided by the fitting of the dominant map in the time window of interest for the EPN (250–350 ms) revealed a significant main effect of target ( $F(1, 29)=6.770$ ,  $p=.014$ ,  $\eta_p^2=.189$ ). This map, which is most negative in frontal sites and gradually becomes most positive in occipital sites, explained more variance for bird targets ( $M=0.197$ ) than for spider targets ( $M=0.182$ ). No significant interaction effect between the cue and target emerged ( $F(1, 29)=0.132$ ,  $p=.719$ ,  $\eta_p^2=.005$ ).

### 5.2.2 | Late positive potential

The extracted GEV, provided by the fitting of the dominant map in the time window of interest for the LPP



**FIGURE 6** Outcome of the spatio-temporal segmentation of the grand average ERP data for the cue for each condition separately. During the time interval corresponding to the CNV component (1500–2000 ms), two different topographies were identified, one for each cue (bird cue on the upper row, spider cue on the lower row; see also Figure 3).



**FIGURE 7** Outcome of the spatio-temporal segmentation of the grand average ERP data for the target for each condition separately. During the time interval corresponding to the EPN component (250–350 ms), a main topography emerged that was shared between all conditions. A different topography emerged for the LPP component (400–700 ms), but similarly to the EPN, this main LPP topography was similar for all conditions.

(400–680 ms; the end of the time window in which the map was expressed) revealed no significant effects (all  $p$ s > .14). Similar to the EPN, this map was most negative

in frontal sites and gradually becomes most positive in occipital sites. Following visual inspection of the LPP (see Panel a of Figure 5), fitting was also conducted on a



smaller time window, from 400 to 500 ms post-stimulus. This additional fitting showed significant differences between congruent and incongruent bird target conditions ( $M$  of GEV for spider cue-bird target condition = 15.1%;  $M$  of GEV for bird cue-bird target condition = 17.6%,  $t(29) = -3.33$ ,  $p = .002$ , Cohen's  $d = -0.608$ ), but not between spider target conditions ( $M$  of GEV for bird cue-spider target condition = 18.5%;  $M$  of GEV for spider cue-spider target condition = 17.3%,  $t(29) = 1.01$ ,  $p = .321$ , Cohen's  $d = 0.184$ ). This result suggests that this congruency effect, which is found for bird targets but not for spider targets, is limited to this specific.

## 6 | DISCUSSION

The aim of the current registered report was to examine the temporal dynamics of the relationship between expectancy and attention toward threat, in order to better understand the mechanisms underlying the prioritization of threat detection. Our previous studies demonstrated that a-priori expectancies influence neutral target (birds) detection, but not threatening target (spiders) detection. However, the specific processing stage(s) and underlying mechanisms of expectancy-attention interaction and selective attention to spiders remain unclear. Thus, in the current study, we aimed at shedding light on the neurotemporal processes that underlie threat expectancy and attention to threat, by using EEG and focusing on specific ERP components. To this end, three ERP components were examined in a modified version of the task: cue-locked CNV was measured to examine anticipatory attention, and target-locked EPN and LPP were measured to assess early and late emotional attention, respectively.

Behaviorally, as expected, an attention bias was found toward spider targets, as participants detecting spiders faster than birds, thus replicating our previous studies (Aue et al., 2013, 2016, 2019) as well as other studies available in the extant literature (e.g., Öhman et al., 2001). Moreover, congruency effects were also found for both targets, as participants reacted faster on congruent trials compared to incongruent trials, for both target types. Of note, in terms of effect size, the congruency effect was larger for bird than spider targets, an asymmetry which is similar to our previous studies.

For the CNV, while the expected main effect toward spider cues was not significant, it was trending in the expected direction, as CNV amplitudes were more negative toward spider cues compared to bird cues. Moreover, topographical analysis showed that during the time interval corresponding to the CNV, spider cues and bird cues lead to two different electric field configurations, suggesting the involvement of different brain regions or networks for

the two cues. In line with previous CNV studies, activity for bird cues was associated a right-lateralized frontal negativity (Brunia, Hackley, et al., 2011; Masaki et al., 2010; Walentowska et al., 2018), while spider cues were associated with a more posterior and left-lateralized negativity. Hence, the results of this exploratory analysis suggest that prior to target onset, anticipatory processing was different for birds compared to spiders.

For the EPN, as expected, the mean amplitude was more negative for spider targets compared to bird targets and no congruency effects emerged. Also in line with our hypotheses, the amplitude of the LPP was more positive for spider targets compared to bird targets, yet it did not change with congruency, when assessed based on the pre-registered analysis. However, exploratory topographical analyses showed that the congruency effect was different for spider versus bird targets during the 400–500 ms interval post-target onset, corresponding to the early phase of the LPP. More specifically, during this interval, a clear congruency effect was found for bird targets, but it was absent for spider targets. Interestingly, this neurophysiological effect and asymmetry closely resembles the behavioral effect found in this as well as in our previous studies (Aue et al., 2013, 2016, 2019). Hence, our new ERP results suggest that spiders, unlike birds, lead to prioritized processing because: (1) they produce a different anticipatory effect following the cue at the CNV level; (2) they yield enhanced target processing at the EPN and LPP levels, which reflect early and late stages of selective attention toward emotional stimuli.

A dissociation was found between behavioral and ERP results, as a congruency effect emerged at the behavioral level but not at the LPP level, even though a congruency effect was expected to be found at the LPP level. These results suggest that the LPP may be more sensitive to threat than it is to predictability and congruency (for similar results, see Johnen & Harrison, 2019). It is important to note that at the methodological level, the current paradigm was modified and adapted from our previously used paradigm (Aue et al., 2013, 2016, 2019) to make it EEG compatible. Specifically, the target duration was reduced from 2500 ms to 800 ms and set size was reduced from 9 pictures (8 distractors) to 4 pictures (3 distractors). These changes may have led to the current results, as the current paradigm may have only allowed the measurement of initial engagement and not of any elaborate search strategies (for a comparison of RTs between the current paradigm and the previously used paradigm, see the Supplementary materials). Specifically, this shorter duration may have encouraged a cue-guided search strategy, unlike longer durations, in which participants would not necessarily need to depend on cues to effectively search for and find the

target (for more, Abado, Richter, et al., 2020; Wolfe, 2021). Despite the differences between paradigms, the overall expected pattern of results emerged, as main effects toward spiders were found in ERP as well as behavioral data.

The topographical CNV results suggest differential preparatory activity for spider cues versus bird cues (in line with ERP results by Amrhein et al. [2005] and Regan and Howard [1995]). Thus, as the CNV reflects anticipatory attention, it can be concluded that attention was directed toward spiders from the cue level, as also reflected in the behavioral findings (i.e., congruency effects). Theoretically, these ERP results suggest that the faster detection of spider targets may be facilitated by pretarget preparation and endogenous attention, as participants prepare more for the encounter of spiders compared to the encounter of birds (for more on preferential processing of evolutionary-relevant stimuli, see Abado et al., 2023; Öhman & Mineka, 2001; Seligman, 1971). Methodologically, one implication of these findings is that future studies should use topographical analyses for the CNV, rather than focus on a handful of electrodes, as it usually done (for more on the advantages of topographical analyses, see Pourtois et al., 2008).

Together, results from the current study suggest that prioritization of threat begins at the pre-stimulus (i.e., expectancy) stage. This effect then continues when the stimulus appears, as there is an early (EPN) effect of emotional attention, which reflects the processing of the emotional value of the target regardless of the preceding cues. This is followed by a later (LPP) more elaborate stage of emotional attention, where emotion is brought together with expectancy, as exhibited by the congruency effects that were found 400–500 ms post stimulus. While the differential effects of expectancy on target were limited to a short interval, the main effect toward spiders lasted longer (until 700 ms post stimulus). These results suggest that effects of expectancy and attention can be sequential as well as interactive (see also Öhman, 1986, for the two-stage model of emotional stimuli perception). Some studies suggest that prioritization of emotional stimuli, at the EPN level as well as the LPP level, is an adaptive behavior that promotes evolutionary success (Schupp et al., 2006; see also Dolcos et al., 2020; Pourtois et al., 2013 for more on emotion–attention interactions).

The current study adds to previous literature in that it measures the temporal unfolding of expectancy processes using the CNV as well as subsequent attentional processes using the EPN and LPP. Thus, while previous studies focused solely on the CNV in non-emotional contexts (e.g., Kóbor et al., 2021; Scheibe et al., 2009), or solely on the EPN and LPP in emotional contexts (for a review, see Schupp et al., 2006), the current study examined emotional expectancy and attentional processes sequentially.

Hence, the current study harnessed the high temporal resolution provided by EEG/ERP measures to better understand the temporal dynamics of expectancy and attention as they take place. While the CNV reflects real-time processing of cues, the LPP reflects congruency effects (i.e., an interaction between cues and targets), thus providing a comprehensive picture of expectancies as well as expectancy violations in emotional contexts. Hence, the current findings emphasize the importance of studying the dissociation, as well as the interaction, between expectancy and attention (for more on the dissociation between expectancy and attention, see Abado, Aue, et al., 2020; Berggren & Eimer, 2019; Summerfield & Egnér, 2009).

The current study recruited an unselected sample for ecological validity. Future studies can examine the CNV in relation to low and high levels of intolerance of uncertainty and with larger sample sizes. At the same time, cues can be made more unpredictable as the present study employed mostly valid cues. Such a manipulation could maximize uncertainty and reveal possible associations between trait intolerance of uncertainty and the CNV (e.g., see Gole et al., 2012; see also Abado, Aue, et al. (2020) for an elaboration on various individual, affective, and motivational factors that affect the interaction between expectancies and attention to threat). Of note, that fact that these results were found among a sample of unselected participants, supports the notion that directing expectancy and attention toward spiders reflects an adaptive evolutionary mechanism (Seligman, 1971; for a review on the neural chronometry of threat-related attentional bias in health and in anxiety, see Gupta et al., 2019; for cognitive biases in health and psychiatric disorders, see Aue & Okon-Singer, 2020).

As mentioned, the current paradigm included a reduced visual array and shorter presentation durations, compared to our previous studies. Future studies can use the previous (longer) paradigm and focus more on later components, such as the LPP. With longer presentation durations, a checking behavior is often exhibited, in which spider fear levels are positively correlated with the time it takes to find bird targets (e.g., Aue et al., 2013; for a meta-analysis on checking behavior in threatening as well as neutral conditions, see Strauss et al., 2020). It would be interesting to see whether this checking behavior is associated with the LPP, which can also be sustained for several seconds following picture onset (e.g., Cuthbert et al., 2000; Hajcak et al., 2010). This would be more clinically relevant in high fear participants. Along the same lines, our own previous work showed that attention bias can be reduced in low fear as well as in high fear participants, using a manipulation of the frequencies of spider/bird targets (Abado, Sagi, et al., 2020). Future studies can explore this change in attention bias using ERPs and examine whether

behavioral/neural changes are associated with a reduction in fear levels.

Taken together, the current results show consistent differential processing of spiders, which is exhibited in three ways: (1) topographical analyses of the CNV showed that spider cues were processed differently than bird cues; (2) both neural (i.e., EPN and LPP) and behavioral results showed prioritized processing of spider targets compared to bird targets; (3) behaviorally, congruency effects were found for both types of targets, although this effect seems to be stronger for bird targets compared to spider targets. In a complementary manner, during a short window of the LPP, a congruency effect was found only for bird targets, while spider targets were unaffected by the previous cues. Together, ERP results show that prioritization of spiders begins at the cue level, before pictures are even presented, and lasts until later processing of targets, at the LPP level. For spider targets, no differences between congruent and incongruent conditions were found during a short time window, after which the effect of spider targets remains. Thus, the effects of expectancy and attention are interactive and dynamic, as expectancy effects are present following cue onset and to a lesser extent following target onset. Following the target onset, the effects of threat are strong and long-lasting.

#### AUTHOR CONTRIBUTIONS

**Elinor Abado:** Conceptualization; data curation; formal analysis; investigation; methodology; project administration; writing – original draft; writing – review and editing. **Tatjana Aue:** Conceptualization; investigation; methodology; software; writing – original draft; writing – review and editing. **Gilles Pourtois:** Conceptualization; formal analysis; investigation; methodology; writing – original draft; writing – review and editing. **Hadas Okon-Singer:** Conceptualization; funding acquisition; investigation; methodology; project administration; resources; supervision; writing – original draft; writing – review and editing.

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#### CONFLICT OF INTEREST STATEMENT

The authors do not report any conflicts of interest.

#### DATA AVAILABILITY STATEMENT

All materials, stimuli, data, scripts, and output files were uploaded onto the OSF website (<https://osf.io/64nzc/>).

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**Table S1.** Means (*M*) and standard deviations (*SD*) for all questionnaires and questions.

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