Attentional suppression is delayed for threatening distractors

Nicolas Burra, Coralie Pittet, Caroline Barras & Dirk Kerzel

To cite this article: Nicolas Burra, Coralie Pittet, Caroline Barras & Dirk Kerzel (2019) Attentional suppression is delayed for threatening distractors, Visual Cognition, 27:3-4, 185-198, DOI: 10.1080/13506285.2019.1593272

To link to this article: https://doi.org/10.1080/13506285.2019.1593272

Published online: 18 Mar 2019.

Submit your article to this journal

Article views: 62

View related articles

View Crossmark data
Attentional suppression is delayed for threatening distractors

Nicolas Burra, Coralie Pittet, Caroline Barras and Dirk Kerzel

Faculté de Psychologie et des Sciences de l’Éducation, University of Geneva, Geneva, Switzerland

ABSTRACT

According to the threat-capture hypothesis, irrelevant-but-salient stimuli interfere more with a visual search task when they are perceived as threatening. We investigated the neural basis for behavioural interference in conditions that promote attentional suppression of distracting stimuli (i.e., easy search with predictable targets). In Experiment 1, participants discriminated the shape of a neutral target (a flower), which competed for selection with a threat-related or neutral distractor (spider or leaf, respectively). In line with prior results, we observed larger behavioural interference from spider than leaf distractors. Electrophysiological recordings revealed a posterior positivity between 200 and 300 ms, the PD, suggesting that participants actively suppressed both leaf and spider distractors. Critically, the PD was delayed with spider compared to leaf distractors. Experiment 2 was a control experiment where we confirmed that the results depended on the execution of the peripheral search task. When participants performed a localization task on the fixation cross, the decisive results from Experiment 1 were not replicated despite equal peripheral stimulation. Our results indicate that the behavioural delay incurred by threatening stimuli is accompanied by a delay of suppressive mechanisms. Conversely, we found no evidence for initial capture followed by suppression that may be predicted by hypervigilance-avoidance theory.

ARTICLE HISTORY

Received 13 August 2018
Accepted 3 March 2019

KEYWORDS

Spider; PD; attentional capture; active suppression; visual search; N2pc

Our brain can only process a limited amount of visual information. The necessary reduction of the amount of information is ascribed to visual selective attention (Desimone & Duncan, 1995; LaBerge, 1995). In recent years, there has been substantial interest in the effect of emotional saliency on attentional selection. Some objects have high attentional priority because of their physical saliency (Pashler, 1988; Theeuwes, 1992), whereas others derive their attentional priority from their affective value (Eastwood, Smilek, & Merikle, 2001; Fox et al., 2000). High attentional priority is given to stimuli associated with a risk of harm or threat to survival. The threat-capture hypothesis (Ohman & Mineka, 2001) suggests that threatening visual objects increase capture of attention compared to non-threatening stimuli. The account states that the preferential selection of threatening objects is rapid, resistant to active top-down attentional control and reliant on an evolutionary old defense system mediated by the limbic system, specifically the amygdala (LeDoux, 1996).

High attentional priority affects different aspects of attentional selection. In visual search tasks, threat-related attentional biases often result in facilitated orienting to threat-related targets, which allows for faster and more accurate responses. Facilitated attentional selection of fear-related targets is well established and is the basis of studies on the anger superiority effect, which refers to the faster processing of threatening (angry) faces compared to happy faces (Bretherton, Eysenck, Richards, & Holmes, 2017; Mineka & Ohman, 2002; Öhman, 1996; Williams, Watts, MacLeod, & Mathews, 1988). Neural measures revealed that the anger superiority effect is indeed mediated by the enhanced allocation of attention to threatening stimuli (Feldmann-Wustefeld, Schmidt-Daffy, & Schubo, 2011).

Conversely, preferential processing of threatening stimuli may also elicit interference in visual search tasks. In particular, the threat-capture hypothesis predicts that threatening stimuli capture attention despite being irrelevant for the ongoing task. One possibility to measure attentional captured by a salient-but-irrelevant stimulus is the additional singleton paradigm, which assesses the precedence of bottom-up over top-down control of attention (Theeuwes, 1991). It was observed that irrelevant...
angry faces produced more interference than happy faces (Burra, Barras, Coll, & Kerzel, 2016; Burra, Coll, Barras, & Kerzel, 2017; Hodsoll, Viding, & Lavie, 2011; Huang, Chang, & Chen, 2011), suggesting that threatening stimuli increase bottom-up control of attention.

In addition to certain facial expressions, animals such as snakes or spiders also carry threat value (Ohman, Flykt, & Esteves, 2001). Spiders in particular are a common object of phobias, but are also rated negatively by healthy participants. Similar to angry faces, facilitated orienting to spider relative to neutral targets has been demonstrated in various tasks, such as the dot probe task (Lipp & Derakshan, 2005; Mogg & Bradley, 2006), visual search tasks (Ohman, Lundqvist, & Esteves, 2001; Soares, Esteves, Lundqvist, & Ohman, 2009), or object identification tasks (Kolassa, Musial, Mohr, Trippe, & Mittner, 2005). Moreover, behavioural studies provided evidence for stronger attentional capture by spider relative to neutral distractors in visual search tasks (Lipp & Waters, 2007; Mittner, Krieschel, Hecht, Trippe, & Weiss, 2004; Rinck, Reinecke, Ellwart, Heuer, & Becker, 2005). That is, search was slower in the presence of a task-irrelevant spider as compared to a non-spider distractor. Thus, both facilitated target search and stronger distractor interference have been taken to support the high priority of threatening stimuli in attentional selection.

To provide further evidence for the rapid attentional processing of threat-related stimuli, especially faces, studies were conducted using the N2pc component, a marker of spatial attentional selection (Burra et al., 2016; Feldmann-Wustefeld et al., 2011; Weymar, Gerdes, Low, Alpers, & Hamm, 2013). The N2pc is observed at posterior-occipital electrodes approximately 180–300 ms after display onset (Eimer, 1996; Luck & Hillyard, 1994), and corresponds to a more negative voltage at electrode sites contralateral than ipsilateral to an attended item. The N2pc revealed enhanced attentional selection of spiders at an early stage of visual processing in spider-fearful participants. In Weymar et al. (2013), participants were required to detect the presence of an odd stimulus in an array of six items. The N2pc amplitude to spiders was larger for spider-fearful compared to non-fearful participants, confirming that threatening stimuli capture attention more than neutral stimuli. Similar results were observed with other phobias, such as blood or social phobia (Buodo, Sarlo, Munafò, & Palomba, 2009; Reutter, Hewig, Wieser, & Osinsky, 2017).

Beyond attentional capture by salient distractors, recent research has focused on mechanisms that avoid distraction by salient stimuli. Most recently, Gaspeni and Luck (2018b) reviewed evidence for the idea that distraction by salient stimuli is avoided by top-down suppression. Key evidence for distractor suppression is a contralateral positivity at the same electrode sites and in the same time range as the N2pc, the distractor positivity or P0 (Hickey, DiLollo, & McDonald, 2009). The P0 has been observed in segmentation or detection task (Feldmann-Wustefeld, Brandhofer, & Schubo, 2016; Feldmann-Wustefeld & Schubo, 2013, 2016; Feldmann-Wüstefeld & Vogel, 2018), but the current research focused on variants of Theeuwes’ (1992) additional singleton paradigm. In the additional singleton paradigm, participants search for a target stimulus defined on one perceptual dimension, while the distractor stimulus is defined on another dimension. In the most frequently used version of the paradigm, participants search for a shape target. When a colour distractor is shown, RTs increase compared to distractor-absent trials. Presentation time of the search display is typically unlimited, which is an important aspect because electrophysiological correlates of distractor processing change if stimuli are only briefly presented (Kiss, Grubert, Petersen, & Eimer, 2012). In many studies using the typical version of the additional singleton paradigm, a P0 to the salient colour distractor was observed between 180 and 300 ms after stimulus onset (Burra & Kerzel, 2013, 2014; Gaspar, Christie, Prime, Jolicoeur, & McDonald, 2016; Gaspar & McDonald, 2014; Gaspelin & Luck, 2018a; Jannati, Gaspar, & McDonald, 2013).

A distractor-related positivity was also observed before the N2pc interval, between 100 and 200 ms, which may reflect an early saliency (Barras & Kerzel, 2016, 2017; Fortier-Gauthier, Moffat, Dell’Acqua, McDonald, & Jolicoeur, 2012; Gokce, Geyer, Finke, Muller, & Tollner, 2014; Jannati et al., 2013), or “attend-to-me” signal (Sawaki & Luck, 2010). The positivity may also occur later, between 300 and 400 ms, where it may reflect the termination of an attention shift (Hilimire, Mounts, Parks, & Corballis, 2011; Liesefeld, Liesefeld, Tollner, & Muller, 2017; Sawaki, Geng, & Luck, 2012).

In the present study, we refer to the early positivity between 100 and 200 ms as Ppc (Barras & Kerzel, 2016,
2017; Fortier-Gauthier et al., 2012; Gokce et al., 2014; Jannati et al., 2013) even though it is not quite clear whether it is functionally separate from the $P_D$ in the 200–300 ms interval (Barras & Kerzel, 2017; Weaver, van Zoest, & Hickey, 2017).

Recent research has also uncovered the conditions that determine whether a salient stimulus in the additional singleton paradigm can be suppressed. Burra and Kerzel (2014) and Kiss et al. (2012) showed that a colour distractor elicits an N2pc (i.e., attentional capture) when the target and nontarget shapes switch roles in an unpredictable manner. In contrast, predictable target and nontarget stimuli result in a $P_D$ to the colour distractor (Burra & Kerzel, 2013; Jannati et al., 2013), suggesting that the distractor was suppressed. Because random swaps between target and distractor result in slower search times than predictable targets (Lamy & Yashar, 2008; Pinto, Olivers, & Theeuwes, 2005), one may conclude that easy search tasks allow for distractor suppression while difficult search results in attentional capture by the distractor. Consistent with this idea, increasing search difficulty through target-nontarget similarity resulted in capture by the colour distractor (i.e., an N2pc to the distractor) even though the search target was perfectly predictable (Barras & Kerzel, 2017). However, both suppression (Bretherton et al., 2017; Burra et al., 2017) and capture (Burra et al., 2016; Eimer & Kiss, 2007) were observed with predictable targets and threatening faces as distractors. Because the search tasks were easy, a $P_D$ to salient distractors was expected throughout. Therefore, threat may increase the attentional priority of a stimulus so that it causes attentional capture (i.e., a distractor-related N2pc) in conditions that would typically allow for suppression (i.e., a distractor-related $P_D$).

In the present paper, we asked whether attentional suppression of threatening stimuli differs from the attentional suppression of neutral stimuli. It is not clear what to predict based on the facilitated attentional deployment to threatening targets that we reviewed above. Possibly, the expected attentional suppression of threatening distractors is cancelled by the high attentional priority of threat stimuli. It was shown that the $P_D$ and N2pc components are additive so that capture and distraction jointly determine the amplitude and sign of the voltage difference (Gaspar & McDonald, 2014; Hickey, McDonald, & Theeuwes, 2006; Liesefeld et al., 2017). Thus, neutral stimuli may be suppressed, while attentional capture cancels the positivity either completely or partially. Another prediction is made by the hypervigilance-avoidance hypothesis (Mogg & Bradley, 2006), which was developed in the context of anxiety. Fearful or phobic participants initially respond to the feared object (e.g., a spider) by hypervigilance combined with fear. Subsequently, they avoid the feared object by directing attention elsewhere. While we are not concerned with phobic populations, it is nonetheless possible to adopt the hypothesis to non-fearful participants. In particular, it may be possible that threatening stimuli result in attentional capture followed by suppression, whereas non-threatening stimuli can be immediately suppressed. Thus, there would be a sequence of capture followed by suppression for threatening distractors. A similar sequence was observed when the distractor resembled the target and was therefore initially attended (Hilimire et al., 2011; Liesefeld et al., 2017).

**Experiment 1**

In this study, we compared the electrophysiological signatures of suppression with threatening and non-threatening distractors. To isolate distractor from target processing, the target was presented on the vertical meridian while the distractor was presented on a lateralized position. In this configuration, the difference between contra and ipsilateral electrodes at posterior sites (i.e., the N2pc or $P_D$) only reflects distractor processing (Woodman & Luck, 2003). Further, the target and distractor stimuli never swapped roles and the search task was easy, so that we expect a $P_D$ to the distractor (Barras & Kerzel, 2017; Burra & Kerzel, 2014). Further, based on the hypervigilance-avoidance hypothesis, we predict that threatening distractors result in attentional capture (N2pc) followed by attentional suppression ($P_D$), while neutral distractors only elicit suppression.

To dissociate effects of visual saliency and threat, we presented not only a threatening spider distractor, but also a non-threatening leaf distractor. Leaf and spider distractors were equally salient and visually similar so that behavioural or electrophysiological differences can be attributed to threat.

Participants were instructed to indicate the position of a missing petal in the upper part of the flower stimulus. Therefore, the leaf and the spider stimuli were irrelevant to the task and there was no incentive
to attend to them (Theeuwes, 2010; Yantis & Egeth, 1999). The non-targets were also flower stimuli with a missing petal in the lower central position, which made them easy to discriminate from the target stimulus while at the same time balancing visual contrast and spatial frequency.

**Materials and method**

**Participants**

Twenty-one students enrolled in a first year psychology class at the University of Geneva (all female) participated in the experiment. According to self-report, participants had normal or corrected-to-normal vision and were free of neurological or psychiatric conditions. All participants were naive regarding the purpose of the experiment. The local ethics committee of the University of Geneva had approved the study, and informed consent was obtained from participants prior to the experiment. Due to excessive eye blinks and saccades, three datasets were discarded, resulting in 18 participants (age: $M = 21.1$, $SD = 3.7$ years) for all subsequent analyses.

**Stimuli**

Six stimuli were presented at 4.5° of eccentricity on a black background. The approximate size of the stimuli was 3° horizontal × 4° vertical. The target and nontargets were flowers with a missing petal in the lower central position, which made them easy to discriminate from the target stimulus while at the same time balancing visual contrast and spatial frequency.

To match the luminance of distractor stimuli, the spider and leaf images were composed of the same number of black pixels (~16800). All pictures were black and white and the background was white.

**Apparatus and procedure**

The experiment took place in a dimly lit room. The Cogent toolbox (www.vislab.ucl.ac.uk/Cogent2000) for MATLAB was used to display the stimuli. All stimuli were displayed on a CRT screen. The target consisted of a flower with a missing petal on the upper left or right. The missing petal of the target flower and the location of the target varied unpredictably. A distractor object (50% spider, 50% leaf) was present in two-thirds of the trials, similar to previous studies on attentional capture (Burra et al., 2016; Burra et al., 2017; Burra & Kerzel, 2013, 2014; Hickey

![Diagram of stimuli and apparatus](image-url)

**Figure 1.** (A) Stimuli in the visual search task. The target was a flower with a missing petal in the upper part and participants were asked to judge whether the gap was on the left or right. Nontargets were flowers with a missing petal below the centre. A spider and a leaf were used as distractor stimuli. The search array was displayed until a response was registered. (B) Illustration of the trial sequence. The first trial shows a vertical target and lateral distractor. The second trial shows a distractor-absent trial with a lateral target. Event-related potentials were only analyzed for these configurations.
et al., 2006). On half of the distractor-present trials, the target was on the vertical midline and the distractor on a lateral position, which elicited a lateralized component to the distractor but none to the target. To make target and distractor positions unpredictable, the distractor appeared ipsilateral on 25% of the distractor-present trials and contralateral on the remaining 25% distractor-present trials. No other conditions were included. As the latter conditions do not test our experimental hypothesis and only a small number of trials was acquired in these conditions, they were not analyzed.

As depicted in Figure 1(B), each trial began with a black fixation cross on a white background for a random interval between 600 and 1200 ms. Participants were instructed to report the orientation of the missing petal as quickly as possible while maintaining accuracy better than 90%. Participants were instructed to respond using their right hand to press one of two keys on a standard keyboard. Incorrect responses were indicated by visual feedback. The stimulus remained on the screen until a response was given, followed by 1000 ms of blank screen. Before the experiment, participants completed 96 trials of the task in which they were trained to avoid moving their eyes in the direction of the target. Each participant performed 12 blocks of 96 experimental trials for a total of 1152 trials. Prior to the experiment, participants completed a questionnaire regarding their fear of spiders (Szymanski & O’Donohue, 1995) in its French Version (Delroisse & Philippot, 2007).

After completing the experiment, participants evaluated the stimuli in order to assess their subjective experience of threat. Participants evaluated the degree to which the stimuli were pleasant (from 0 = very unpleasant to 100 = very pleasant), arousing (from 0 = not stimulating to 100 = extremely stimulating), frightening (from 0 = no fear to 100 = extreme fear), and disgusting (from 0 = no disgust to 100 extreme disgust) similar to a previous study (Devue, Belopolsky, & Theeuwes, 2011).

Electrophysiological recording and analysis
EEG signals were recorded using an actiCHamp amplifier (Brain Products, Gilching, Germany) with active Ag/AgCl electrodes sampled at 1000 Hz. Twenty-seven electrodes were fixed on the scalp, one on the outer canthus of each eye (HEOG), one above and below the right eye (VEOG), and one on each earlobe. Cz served as the online reference and AFz as the ground. Electrode impedance was kept below 20 kΩ for EEG and H/VEOG.

Using BrainVision Analyzer 2.1 (Brain Products, Gilching, Germany), data were filtered with a Butterworth zero-phase shift low-pass filter (40 Hz with 24 dB/oct.). Trials with eye movements (HEOG ± 25 μV), blinks (VEOG ± 60 μV) or general artifacts (all electrodes ± 80 μV) were discarded. The same parameters were used throughout the study. On average, applying these criteria left 318 trials (17% exclusions) in the no distractor condition, 167 trials (12% exclusions) in the spider distractor condition and 153 trials (20% exclusions) in the leaf distractor condition. Epochs started 100 ms before the onset of the display and ended 600 ms after, for a total time window of 700 ms. When necessary, we corrected for the non-sphericity of the data in the ANOVA using the Greenhouse-Geisser correction of the degrees of freedom.

The N2pc/PD mean amplitudes were measured at pooled electrodes PO7/PO8 and P7/P8, where the signal was maximal. At these sites, we extracted the mean amplitude at its apex, that is, between 230 and 330 ms after stimulus onset. Visual inspection revealed an early positive component, so that we also analyzed the interval from 90 to 130 ms. Moreover, we measured latencies using the jackknife-based scoring method (Miller, Patterson, & Ulrich, 1998). We derived ERP onset and offset latency for the PD in the distractor conditions using a relative amplitude criterion of 50% of maximum amplitude before and after the peak of the component respectively. All jackknife-based latency estimates were then submitted to a paired-sample t-test. The resulting t-values were corrected using the formula $t_C = t / (n - 1)^2$, where $t_C$ represents the corrected t value, and n represents the number of participants (Kiesel, Miller, Jolicoeur, & Brisson, 2008).

Behavioural results
Fear of spiders questionnaire
The mean score was 59.5 (range: 22–90; SD: 24.92).

Ratings
We performed four one-way, repeated measures ANOVAs to evaluate effects of stimulus type (flower, leaf, spider) on rated pleasantness, arousal, fear and disgust. As expected, stimulus type had a significant
effect on all measures (see Table 1), $F(2, 34) > 14.5$, $p < .001$, $\eta^2_p > .460$. Post-hoc analysis indicated that spiders were rated as more unpleasant, more arousing, more frightening and more disgusting than flowers and leaves, $t(17) > 3.57$, $p < .002$. Leaf and flower stimuli were not rated as significantly different from one another on any measure, $t(17) < 1.88$, $p > .08$.

**Reaction times and accuracy**
A one-way (distractor type: no distractor, spider distractor, leaf distractor), repeated-measures ANOVA revealed that RTs were shorter on distractor-absent trials (619 ms) than on trials with spider (640 ms) and leaf (633 ms) distractors, $F(2, 34) = 15.26$, $p < .001$, $\eta^2_p = 0.473$. Critically, a paired t-test revealed that RTs were longer with spider than leaf distractors (640 vs. 633 ms), $t(17) = 2.32$, $p = .033$, Cohen’s $d = 0.55$. Additionally, accuracy was higher on distractor-absent trials (0.96) than on trials with spider (0.95) and leaf (0.94) distractors, $F(2, 34) = 3.49$, $p = .042$, $\eta^2_p = 0.171$. However, there was no significant difference between spider and leaf distractors, $t(17) = 1.22$, $p = 0.23$.

**Electrophysiological results**

**Global N2pc/P_D amplitudes (230–330 ms)**
The difference waves obtained by subtracting ipsi- from contralateral activity are shown in Figure 2(D), while ipsi- and contralateral waveforms are shown in Figure 2(A–C). A one-way ANOVA (lateral stimulus: target, spider distractor, leaf distractor) was conducted on mean difference amplitudes. A significant effect of lateral stimulus was revealed, $F(1.24, 21.10) = 49.15$, $p < .001$, $\eta^2_p = .74$. The voltage difference was negative to targets (−1.29 µV), consistent with an N2pc, but it was positive to spider (2.16 µV) and leaf (2.11 µV) distractors, consistent with a P_D. There was no significant

---

### Table 1. Mean ratings of the three stimuli in Experiment 1.

<table>
<thead>
<tr>
<th></th>
<th>Flower</th>
<th>Leaf</th>
<th>Spider</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleasantness</td>
<td>57.3 (3.13)</td>
<td>64 (3.6)</td>
<td>21.4 (3.95)</td>
</tr>
<tr>
<td>Arousal</td>
<td>22 (5.34)</td>
<td>12.8 (5.83)</td>
<td>45.8 (5.8)</td>
</tr>
<tr>
<td>Fear</td>
<td>13 (4.8)</td>
<td>4.5 (4.3)</td>
<td>38.94 (6.3)</td>
</tr>
<tr>
<td>Disgust</td>
<td>17.1 (5.4)</td>
<td>9.2 (5.2)</td>
<td>41.6 (6.8)</td>
</tr>
</tbody>
</table>

Note: Standard errors are given in parenthesis.

---

**Figure 2.** Electrophysiological results from Experiment 1. In the search displays, the target was the flower with a petal missing on the upper left or right. It was shown without distractor (A), with a spider (B) or a leaf (C) distractor. Panels A–C show the mean voltages at ipsi- and contralateral electrodes PO7/8 and P7/8 (pooled). Panel D shows the difference waveforms between contralateral and ipsilateral electrodes with respect to the target location (in the absence of a distractor), and with respect to the spider and leaf distractor locations.
difference between spider and leaf distractors, t(17) = 0.28, p = .77. The negative (N2pc) and positive (Pd) components were significantly larger than zero, ts(17) > 4.05, ps < .001, Cohen’s ds > .95.

**Onset/offset of distractor suppression**

As can be seen in Figure 2(D), the Pd to the spider distractor appears to start and end later than the Pd to the leaf distractor. However, using the jackknife procedure, we only confirmed that the offset (spider vs. leaf: 337 vs. 316 ms), t(17) = 3.48, p = .003, was delayed. In other words, suppression of the spider distractor occurred approximately 21 ms later than suppression of the leaf distractor.

Because this results was unexpected, we replicated the study (see Supplementary Experiment 1), which confirmed the presence of the delay (offset of the Pd, spider vs. leaf: 336 vs. 318 ms), t(17) = 2.93, p = .009. In other words, suppression of the spider distractor implied a delay of approximately 18 ms compared to the suppression of the leaf distractor.

**Time-course of distractor suppression**

We further assessed the temporal dynamics of attentional suppression of spider and leaf distractors by analyzing mean difference amplitudes (contra minus ipsi) in four 50 ms-time windows starting 150 ms after stimulus onset. We ran a 4 (50 ms time intervals: starting at 150, 200, 250 and 300 ms) × 2 (distractor type: spider, leaf) on the mean difference amplitudes. We found a main effect of time, F(3, 51) = 23.91, p < .001, ηp² = .58, but no main effect for distractor condition, p = .319. Critically, there was an interaction between time interval and distractor type, F(3, 51) = 8.13, p < .001, ηp² = .32. Post-hoc analysis revealed that the leaf distractor elicited a more positive difference amplitude than the spider distractor in the time windows from 150 to 200 ms (0.35 vs. –0.05 μV), t(17) = 2.63, p = .018, Cohen’s d = 0.62, and from 200 to 250 ms (1.59 vs. 1.14 μV), t(17) = 2.1, p = .046, Cohen’s d = 0.51. Critically, in the 300–350 ms time window, the difference amplitude was more positive for the spider than the leaf distractor (1.64 μV vs. 1.17 μV, respectively), t(17) = 2.39, p = .029, Cohen’s d = 0.56. The time course analysis suggests that the Pd to the spider was delayed.

**Early positive deflection**

Inspection of Figure 2(D) suggests that there was a positive deflection to distractor stimuli in the time range of the Ppc (100–200 ms). We ran a one-way (distractor type: no distractor, spider distractor, leaf distractor) ANOVA on the difference amplitudes between 90 and 130 ms after stimulus onset. There was a statistically significant effect, F(2, 34) = 7.49, p < .002, ηp² = .31. Post-hoc analysis revealed that the mean difference amplitudes occurring in the no distractor condition (~0.17 μV) were different from both distractor conditions (0.7 μV for spider and 0.53 μV for leaf), ts(17) > 2.49, ps < .023, Cohen’s ds > .58. However, the difference amplitudes for spider and leaf distractors were not statistically different, t(17) = 1.17, p = .30. Further, the difference amplitudes for spider and leaf distractors were significantly different from zero, ts(17) > 4.85, ps < .001, Cohen’s ds > 0.72, consistent with the occurrence of a Ppc, while the difference amplitude in the no distractor condition was not significantly different from zero, t(17) = 0.13, p = .89.

**Discussion**

We investigated attentional suppression of threatening and non-threatening distractors (i.e., spider vs. leaf). Conditions were selected to promote the suppression of salient-but-irrelevant stimuli. Importantly, the search task was easy because there was little similarity between target and nontargets or between target and distractor. In addition, the target stimulus was predictable, as it did not swap roles with the non-target stimuli. We found that the presence of a spider distractor increased RTs more than a leaf distractor, probably because spiders have a higher attentional priority. The electrophysiological data confirmed that both spider and leaf distractors resulted in a Pd, suggesting that both stimuli were attentionally suppressed. However, suppression of the spider distractor occurred approximately 18 ms later than suppression of the leaf. Critically, we replicated this result in order to assess the reliability of our results (see Supplementary Experiment 1).

With respect to the hypervigilance-avoidance hypothesis, we did not find attention to be initially captured by threatening stimuli. That is, there was no N2pc to the spider distractor. Rather, avoidance, as indexed by the Pd, was delayed relative to neutral distractors. Thus, instead of the expected sequence of capture and suppression, we found delayed suppression for threatening stimuli. In addition, the amplitude of the Pd was not different, which suggests that threatening
stimuli are not met with more suppression, but only with delayed suppression.

**Experiment 2**

There is a potential caveat in Experiment 1. It is possible that visual differences between the spider and leaf distractors accounted for the delayed suppression. Despite our efforts to match visual aspects of the distractor stimuli, the remaining differences (e.g., in terms of visual spatial frequencies) might explain the electrophysiological differences (Luck & Hillyard, 1994). Further, the early positivity to both distractors, which we labelled Ppc (Fortier-Gauthier et al., 2012; Jannati et al., 2013; Leblanc, Prime, & Jolicouer, 2008), attests to the presence of local feature discontinuities and these discontinuities may guide later attentional processes (Sawaki & Luck, 2010).

It may even be possible that the imbalanced saliency between spider and leaf distractors fully accounts for the differential delay of suppression. To rule out this possibility, we introduced a foveal task to reduce attention to the peripheral search displays (Burra & Kerzel, 2014; Sawaki & Luck, 2010). In Experiment 2, participants were required to localize a missing pixel on the fixation cross. We hypothesized that low-level differences would continue to influence the lateralized ERP, even if the stimulus was mostly ignored. If the differential delay of the suppression effect were only based on stimulus characteristics, we would observe the same results as in Experiment 1.

**Materials and method**

**Participants**

Nineteen students (2 male) with the same characteristics as in Experiment 1 participated. One female participant’s data were removed due to excessive eye movements, resulting in 18 participants for all subsequent analyses (age: $M = 22$ years, $SD = 3.25$, not significantly different from Experiment 1, $p = .54$).

**Stimuli, apparatus, procedure, electrophysiological recording and analysis**

Experiment 2 was similar to Experiment 1 with the following exceptions. Participants were required to indicate the location of a missing pixel on the vertical line of the fixation cross by responding with one of two keys (left and right arrow keys) on a standard keyboard with their right hand. “Upper” and “lower” responses were equally likely. Due to technical problems, the data of four participants could not be used for the analysis of stimulus ratings. On average, 342 trials (11% exclusions) were left in the no distractor condition, 172 trials (11% exclusions) in the spider distractor condition and 158 trials (17% exclusions) in the leaf distractor condition.

**Results**

**Behavioural results**

**Fear of spiders questionnaire**

The mean score was 46.11 (range: 18–95; SD: 24.47), which was not significantly different from Experiment 1, $t(34) = 1.62$, $p = .113$.

**Ratings**

Analyses were performed on the data from 14 participants. One-way, repeated-measures ANOVAs showed the expected effects of stimulus type (spider, leaf, flowers) on ratings of pleasantness, arousal, fear and disgust (see Table 2), $F$s(2, 26) $> 11.48$, $p$s $< .001$, $\eta^2_p > 0.469$. Post-hoc analysis indicated that spiders were rated as more unpleasant, more arousing, more frightening and more disgusting than flowers and leaves, $t$s(13) $> 3.3$, $p$s $< .005$. The ratings of leaf and flower stimuli were not significantly different concerning arousal, fear and disgust, $t$s(13) $< 2.01$, $p$s $> .07$. However, participants rated the leaf as more pleasant than the flower, $t(13) = 2.85$, $p = .014$. Spider and leaf scores were not significantly different from ratings in Experiment 1, $t$s(30) $< 1.48$, $p$s $> .16$.

**Reaction times and accuracy**

A one-way (distractor type: no distractor, leaf distractor, spider distractor) ANOVA on RTs, $F(2, 34) = 0.71$, $p = .49$, and accuracy, $F(2, 34) = 0.22$, $p = .79$, did not find any significant effects. Overall, mean RT was 506 ms and mean accuracy was .97.

**Table 2.** Mean ratings of the three stimuli in Experiment 2.

<table>
<thead>
<tr>
<th></th>
<th>Flower</th>
<th>Leaf</th>
<th>Spider</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleasantness</td>
<td>55.6 (5.9)</td>
<td>68.9 (4.1)</td>
<td>28.3 (5.87)</td>
</tr>
<tr>
<td>Arousal</td>
<td>14.2 (5.2)</td>
<td>3.6 (1.8)</td>
<td>50.5 (8.2)</td>
</tr>
<tr>
<td>Fear</td>
<td>5.21 (2.3)</td>
<td>1.57 (0.7)</td>
<td>41.92 (9.6)</td>
</tr>
<tr>
<td>Disgust</td>
<td>4.35 (2.5)</td>
<td>0.71 (0.3)</td>
<td>36.1 (10.4)</td>
</tr>
</tbody>
</table>

Note: Standard errors are given in parenthesis.
Electrophysiological Results

Global N2pc/PD amplitudes (230–330 ms)
Mean difference waves are shown in Figure 3(D), while contra- and ipsilateral waveforms are shown in Figure 3(A–C). A one-way ANOVA (lateral stimulus: target, spider distractor, leaf distractor) on difference amplitudes (contra minus ipsilateral) during the 230–330 ms time period revealed a significant effect of distractor type, $F(2, 34) = 5.57, p = .008, \eta_p^2 = .25$. The PD to the target in the absence of distractors (0.2 µV) was smaller than the PD to the leaf and flower distractors (0.63 and 0.69 µV), $t_{(17)} > 2.62, ps < .018$, Cohen’s $d_s > 0.62$. However, the PD did not differ between leaf and spider distractors (0.63 vs. 0.69 µV), $p = .68$, and was significant in both conditions, $t_{(17)} > 2.59, ps < .019$, Cohen’s $d_s > 0.61$.

Onset/offset of distractor suppression
There was no significant difference in onset or offset of the PD between spider and leaf distractor conditions, $t_{(17)} < 0.53, ps > .6$.

Time-course of distractor suppression
We assessed the temporal dynamics of attentional suppression by analyzing amplitudes in 50 ms-time windows between 150 and 350 ms. We ran a 4 (50 ms time intervals: starting at 150, 200, 250 and 300 ms) × 2 (distractor type: spider, leaf) ANOVA on the mean difference amplitudes. There was no significant interaction between distractor type and time interval, $F(2, 34) = 0.45, p = .64$, or a significant main effect of time, $F(1.3, 22.24) = 0.6, p = .55$, or distractor type, $F(1,17) = 0.03, p = .86$. However, one-sample t-tests revealed that the PD in the distractor conditions were significant, $t_{(17)} > 3.78, ps < .001$, Cohen’s $d_s > 0.89$.

Critically, by including the factor experiment in the ANOVA, we established that the temporal dynamics of attentional suppression differed significantly between Experiments 1 and 2, as evidenced by a significant three-way interaction of time interval, distractor, and experiment, $F(3, 102) = 3.22, p = .026, \eta_p^2 = .09$. This effect highlights the different time course of suppression between spider and leaf distractors in Experiment 1 and the absence of any difference in Experiment 2.

Figure 3. Electrophysiological results from Experiment 2. In the search displays, the target was a missing pixel on the fixation cross. An array of flowers without distractor (A), with a spider distractor (B) or with a leaf distractor (C) were presented, similar to Experiment 1. Panels A–C show mean voltages at ipsilateral and contralateral electrodes PO7/8 and P7/P8 (pooled). Panel D shows the difference waveforms between contralateral and ipsilateral electrodes with respect to the target location (in the absence of a distractor), and with respect to the locations of spider and leaf distractors.
**Early positive deflection**

Analysis of the mean difference amplitudes in the early interval from 90 to 130 ms revealed a main effect of distractor type (none, spider distractor, leaf distractor), $F(1.45, 24.65) = 6.00, p < .013, \eta^2_p = .43$. Post-hoc analysis revealed that mean difference amplitude to the target without distractor (−0.04 µV) was different from the distractor conditions (leaf: 0.39 µV; spider: 0.61 µV), $t(17) > 2.7, p < .013$, Cohen’s $d > .65$. However, there was no statistically significant difference between spider and leaf distractors, $t(17) = 1.13, p = .27$. We conducted t-tests against zero to confirm that the Ppc was present in the pooled distractor-present conditions, $t(17) = 5.04, p < .001$, Cohen’s $d = 1.18$, but not in the distractor-absent condition, $t(17) = 0.31, p = .75$.

**Discussion**

When there was no search task and attention was focused on the fixation point, the results changed dramatically compared to Experiment 1, suggesting that low-level visual differences between spider and leaf distractors cannot account for the results observed in Experiment 1. Unlike in Experiment 1, the presence of a spider distractor did not increase RTs compared to a leaf distractor. Indeed, the distractor-absent condition was not even different from the distractor-present conditions. The electrophysiological results confirmed the early positivity (Ppc) with spider and leaf distractors between 90 and 130 ms, suggesting that it is accounted for by imbalanced saliency and not related to attentional processing. Supplementary Experiment 2 corroborates this conclusion as the Ppc persisted even when the spider stimulus was task-relevant. By relying on the logic of Experiment 3 in Gasperlin and Luck (2018a), we asked observers to indicate the presence of the spider stimulus, which forced observers to attend to the spider. We found that the Ppc to the spider was unchanged, which makes it unlikely that the Ppc was functionally related to distractor suppression. Rather, the current Ppc may reflect differences in sensory adaptation between background and distractor features (Luck & Hillyard, 1994).

Further, the N2pc to the target stimulus disappeared, suggesting that it was not attended. However, both distractors continued to produce a small $P_D$, which may be caused by the sensory imbalance that already caused the Ppc (Jannati et al., 2013). Nonetheless, we cannot rule out that some form of attentional suppression took place because we cannot be sure that all attentional resources were absorbed by the task at central fixation. Therefore, it would be premature to conclude that the residual $P_D$ in the current experiment is unrelated to attentional suppression. Critically, neither the latency and nor the time course of the $P_D$ differed between spider and leaf distractors. Thus, we conclude that the delay of attentional suppression with spider compared to leaf distractors in Experiment 1 was not accounted for by sensory imbalance.

**General discussion**

We investigated the attentional mechanism at work when threatening distractors appear in a visual search task. Given the extant literature, we focused on salient-but-irrelevant spider stimuli. Behaviourally, we observed that RTs were longer with spider compared to neutral distractors. These results are consistent with previous studies (Buetti, Juan, Rinck, & Kerzel, 2012; Devue et al., 2011; Lipp & Waters, 2007; Rinck et al., 2005) and more generally with the threat capture account (Ohman & Mineka, 2001), which states that a threat-related distractor is prioritized over a neutral target. The increase in RTs with spiders compared to leaf distractors in Experiment 1 (replicated in Supplementary Experiment 1) confirms the special status of threat-related stimuli in attentional selection.

The central question of the present study was whether the suppression of threatening stimuli would be different from the suppression of non-threatening stimuli. To answer this question, we created a search task that was likely to yield distractor suppression as reflected in the $P_D$. In particular, we selected an easy search task where target and distractor were highly discriminable and the target was fixed relative to the nontargets. We observed that the amplitude of suppression did not differ between threatening and non-threatening distractors, but the timing was different. Our result are not consistent with the hypothesis that threatening stimuli first capture attention before they are suppressed, which we derived from the hypervigilance-avoidance hypothesis in the context of specific phobias (Mogg & Bradley, 2006). Rather, distractor suppression was delayed for threatening stimuli.
We did not find any difference between spider and leaf distractors in the Ppc interval. Most likely, the Ppc in the current study reflects local feature discontinuity between the homogenous flowers stimuli and the distractors (Luck & Hillyard, 1994). Moreover, we demonstrated in our Supplementary Experiment 2 that the status of the spider (target or distractor) did not modulate the Ppc amplitude. However, our data confirm that the spider distractor was processed differently in the PD interval. Schematic spiders have been shown to have robust influence on attention networks and behaviour (Hartikainen, Siiskonen, & Ogawa, 2012; Vuilleumier & Schwartz, 2001). Do our results conclusively rule out that attention was allocated to the spider? While we did not observe an N2pc to the spider distractors, attentional selection and suppression may have combined to induce the delay of the PD that we observed. According to Hickey et al. (2009), the N2pc reflects the combination of the Nt and PD components. The Nt is related to target enhancement while the PD is related to distractor suppression. In our study, it is likely that the Nt to the distractor, between 200 and 300 ms, was invisible due to the massive suppression between 350 and 500 ms. We speculate that this early short-lived Nt delayed active suppression, as visible in the longer offset latency of the PD in this condition, without resulting in an N2pc. In sum, it may be possible that the presence of a spider delayed the active suppression due to a short-lived attentional component linked to automatic processing of threatening stimuli. Consequently, the PD ended later for the spider compared to the leaf distractor.

In the same vein, it has been demonstrated that interference from spider stimuli reflects delayed disengagement of attention. Gerdes, Alpers, and Pauli (2008) asked participants to search for a colour singleton while ignoring small, task-irrelevant pictures that appeared with an abrupt onset. Phobic participants were significantly slower than control participants on trials with spider distractors, whereas this was not the case for neutral distractors (pictures of mushrooms or flowers). However, the prolonged RTs were not due to more frequent eye movements to spider distractors, but rather to prolonged fixation time on spider compared to other distractors. While the delayed disengagement of overt attention in Gerdes et al. (2008) is at first sight consistent with delayed suppression in the current study, there are important differences.

Gerdes et al. (2008) showed that the allocation of attention was delayed, whereas we show that the attentional suppression was delayed. Further, our results may be related to the proposition that in situations of attentional competition, the outcome reflects the balance between bottom-up (via the amygdala) and top-down (via the prefrontal cortex) processing (Bishop, 2007). In this sense, the presence of a threat-related stimulus may increase the demand for top-down suppression, which slows down the behavioural as well as the electrophysiological response.

Finally, our data limit the scope of the threat capture account (Ohman & Mineka, 2001). The threat capture account claims that threat-related stimuli capture attention automatically, even when outside the focus of attention. However, the results of Experiment 2 do not support this claim. Although participants in Experiment 1 and Experiment 2 had similar fear of spiders and similar ratings of pleasantness, arousal, fear and disgust (see Tables 1 and 2), the PD in Experiment 2 was insensitive to the valence of the distractors. On the one hand, this suggests that the results of Experiment 1 are not due to low-level confounds, but on the other hand, these results challenge the tenets of the threat-capture account. Specifically, they are hard to reconcile with the idea that threat-related stimuli capture attention automatically. Instead, they indicate that depending on the task, top-down control prevents the capture of attention by threatening stimuli. These results are consistent with prior research on physical saliency, which revealed the critical role of the distribution of spatial attention on attentional capture (Belopolsky & Theeuwes, 2010; Kerzel, Born, & Schonhammer, 2012).

Our analysis and discussion have focused on the configuration with lateral distractor and vertical target because it isolates distractor processing (Woodman & Luck, 2003). However, other target-distractor configurations may also provide useful information about attentional capture by salient distractors. For instance, Hickey et al. (2006) found that attention was first captured by a salient colour distractor before it switched to the contralateral target location. Possibly, placing a threatening stimulus opposite to a neutral target would yield a similar pattern because lateralized ERPs could directly mirror the competition between target and threatening distractor. Unfortunately, we cannot answer this
question with the current dataset because of our experimental choices and technical constraints. In particular, we did not have enough trials to calculate reliable means in the ipsi- and contralateral distractor conditions. Future research will have to explore the fate of a treat-related stimulus in this condition.

In conclusion, our study further clarifies the interaction between top-down and bottom-up attention in the processing of irrelevant but threatening distractors. We show that the active suppression of the distractor is modulated by the threat-related value conveyed by the distractor. Concretely, a high threat value of the distractor delays the suppression of the distractor, which subsequently delays the response in the visual search task (Experiment 1 and Supplementary Experiment 1). However, in contrast to some theories suggesting that threat-related distractors bias attentional selection automatically, the results of this study suggest that task demands mediate this effect. When attention is focused on the fixation point, attentional processing is unaffected by threat (Experiment 2).

Taken together, the present results indicate that a threat-related distractor delays suppression relative to a neutral distractor in easy visual search tasks that promote attentional suppression. However, threat-related and neutral distractors were no different when attention was focused on the fixation cross.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**References**


