doi:10.1093/scan/nst044 SCAN (2014) 9, 723–729

Timing the fearful brain: unspecific hypervigilance and spatial attention in early visual perception

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Numerous studies suggest that anxious individuals are more hypervigilant to threat in their environment than nonanxious individuals. In the present event-related potential (ERP) study, we sought to investigate the extent to which afferent cortical processes, as indexed by the earliest visual component C1, are biased in observers high in fear of specific objects. In a visual search paradigm, ERPs were measured while spider-fearful participants and controls searched for discrepant objects (e.g. spiders, butterflies, flowers) in visual arrays. Results showed enhanced C1 amplitudes in response to spatially directed target stimuli in spider-fearful participants only. Furthermore, enhanced C1 amplitudes were observed in response to all discrepant targets and distractors in spider-fearful compared with non-anxious participants, irrespective of fearful and non-fearful target contents. This pattern of results is in line with theoretical notions of heightened sensory sensitivity (hypervigilance) to external stimuli in high-fearful individuals. Specifically, the findings suggest that fear facilitates afferent cortical processing in the human visual cortex in a non-specific and temporally sustained fashion, when observers search for potential threat cues.

Keywords: emotion; hypervigilance; spatial attention; C1; event-related potentials (ERPs)

INTRODUCTION

Voluntary attention to a specific location in the environment results in faster detection and enhanced discrimination for stimuli presented at that location than stimuli at unattended locations. This well-known effect of spatial attention has been demonstrated in striate and extrastriate visual cortical areas (V1–V4; Kastner *et al.*, 1999; Martinez *et al.*, 1999), resulting in increased electrophysiological and hemodynamic activity for attended compared with unattended locations. Recently, Kelly *et al.* (2008) showed that spatial attention may modulate the initial passage of visual input to primary visual cortex (V1). Using event-related potentials (ERPs), the authors observed enhanced amplitudes of the C1 component in response to spatially cued patterns ~50 ms after presenting the visual stimulus. The C1 component has been described for many decades as the earliest cortical component in the visual evoked potential (Regan, 1989). Extensive evidence points to the striate cortex as the neural generator of the C1 (Jeffreys and Axford, 1972, Clark *et al.*, 1995), consistent with its peak latencies ~50–100 ms. The C1 topography evinces pronounced retinotopy, with a voltage reversal over posterior scalp sites reliably related to the location of the stimulus in the upper versus lower visual field. Although best established with systematic manipulation of visual field location, pattern onset at foveal and symmetric locations has been shown to elicit C1 in a robust fashion, given sufficient signal-to-noise ratio (Regan, 1989). Under these conditions, the C1 tends to be negative and widely distributed in topography (Baseler and Sutter, 1997).

Besides spatial attention and perceptual learning (Bao *et al.*, 2010), the C1 has also been described as sensitive to contextual features such as fearful faces and fear-conditioned stimuli (Pourtois *et al.*, 2004, Stolarova *et al.*, 2006), indicating superior evaluation of biologically relevant stimuli at the earliest stage of cortical processing. If biological significance is capable of biasing sensory neurons, then observers high in specific object fear should show sensory facilitation when expecting to confront the feared object. Presently, however, it is unclear how sensory processing varies with inter-individual fear status.

A substantial amount of studies have found that anxious individuals are more vigilant to environmental threat than non-anxious individuals (see for review Bar-Haim *et al.*, 2007; Cisler and Koster, 2010; Yiend, 2010; Miskovic and Schmidt, 2012). For instance, participants reporting fear of spiders (snakes) detect spider (snake) stimuli more rapidly than non-fearful participants, in visual search paradigms (Öhman *et al.*, 2001). Participants high in specific fear also display enhanced N2pc amplitudes in the ERP, indicating enhanced attention capture by these stimuli (Weymar *et al.*, 2013). In the same vein, high-trait anxious individuals detect angry faces faster than low-trait anxious individuals (Byrne and Eysenck, 1995), a difference not observed for happy faces. Similar results were found for socially anxious individuals who show a preferential processing of angry facial expression relative to happy expressions and also shorter responses for angry relative to disgust expressions (Gilboa-Schechtman *et al.*, 1999), pointing to a greater attention bias in anxious individuals. In addition to rapid initial attention capture by threat-relevant stimuli, other studies have shown that high anxious individuals have difficulties disengaging attention from fear-relevant stimuli once they are detected (e.g. Fox *et al.*, 2002; Gerdes *et al.*, 2008). Furthermore, others have proposed that anxious individuals tend to avoid the threat stimulus immediately after detection (Mogg and Bradley, 1998; Pflugshaupt *et al.*, 2005).

Unspecific hypervigilance or heightened alertness even prior to detecting a threat stimulus has previously been described as characteristic of anxious individuals (Beck *et al.*, 1985; Eysenck, 1992). In this perspective, anxious individuals are constantly looking out for signs of threat or harm in their environment and selectively attend to stimuli signaling possible danger. Specifically, Eysenck proposes a broadening of attention (general hypervigilance) during excessive environmental scanning for threat cues followed by a narrowing of attention when a stimulus is being processed (enhanced selective attention). General sensory hypervigilance has also been framed in the defense cascade model based on work in the animal model of defensive behavior (Fanselow, 1994; Lang *et al.*, 1997). According to this model, defensive behavior is characterized by a dynamic sequence of stages: In an initial

Received 2 July 2012; Accepted 28 March 2013
Advance Access publication 1 April 2013

We are grateful to Janine Wirkner for her assistance in data collection. This research was supported in part by a post-doctoral stipend from the German Research Society (Deutsche Forschungsgemeinschaft, DFG) to Mathias Weymar (Forschungsstipendium, WE 4801/1-1).

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pre-encounter stage, the organism is subject to a certain risk (e.g. being in an environment where a threat has been previously encountered), but no immediate danger is present (e.g. the predator has not been detected yet). This stage is characterized by physiological changes that are consistent with threat-unspecific hypervigilance to all stimuli in the environment. As soon as the threat is detected, the stages of post-encounter and, with increasing proximity of the threat, finally of active defensive behavior (fight or flight) are initiated, with sensory perception and motor processes increasingly directed toward adaptive action (Keil *et al.*, 2010). Recent ERP studies with specific phobia individuals indicate that spider fearful and (socially) anxious show enhanced P1 amplitudes to all visual stimuli, irrespective of content, than control individuals (Kolassa *et al.*, 2006, 2007; Michalowski *et al.*, 2009; Mühlberger *et al.*, 2009; Wieser *et al.*, 2010), indicating that such a state of sensory vigilance might be evident in humans as well in contexts they fear.

The present study examined the extent to which specific fear modulates the sensitivity of early afferent electrocortical activity in V1 in participants with small animal fear. To address this issue, we measured ERPs in spider-fearful and non-fearful participants while they searched for discrepant fear-specific and -unspecific objects in visual arrays.

MATERIALS AND METHODS

Participants

664 university students were screened with a German version of the 31-item Spider Phobia Questionnaire (SPQ; Hamm, 2006). Total SPQ score can range from 0 to 31, with higher scores indicating greater fear of spiders. Scales left incomplete or mismarked were excluded from analysis. The final sample consisted of 541 students. Twenty-five spider-fearful individuals (22 female, 3 male; mean age: 21.1 years; 2 left-handed) and 25 non-anxious control participants (19 female, 6 male; mean age: 24.8 years; 2 left-handed) were selected based on their scoring points. Subjects reporting elevated spider fear were included in the spider-fearful group (mean: 19.64, range: 17–28; s.d.: 3.40) if scores were $\geq$17 in the SPQ (88th percentile of the distribution). Twenty-five participants reporting lower levels of spider fear (mean: 3.20, range: 0–7; s.d.: 1.80) were in the non-anxious control group with scores $\leq$7 in the SPQ (56th percentile of the distribution). The distribution of the mean scores of the student sample was similar to normative data of the SPQ (Klorman *et al.*, 1974). Mean scores of the spider-fearful group were slightly lower compared with clinical samples diagnosed with specific phobia animal type (e.g. Mean = 23.76, Fredrikson, 1983; Mean = 23.2, Muris and Merckelbach, 1996). As expected, spider-fearful participants scored significantly higher on the SPQ than the controls [$F(1,48) = 455.83$, $P < 0.001$, $\eta_p 2 = 0.91$]. All had normal or corrected-to-normal visual acuity. All participants gave their informed consent for the protocol approved by the Review Board of the University of Greifswald and received either course credit or financial compensation for participation. The same sample of participants was included in analyses performed in another study (Weymar *et al.*, 2013). Two subjects (one spider-fearful subject) were excluded owing to poor electroencephalogram (EEG) quality.

Stimulus materials and procedure

Participants were seated in a dimly lit sound-attenuated cabin, viewing a 20" computer monitor (1024 × 768, 60 Hz) located 1.5 m in front of the viewer. Each search display contained six objects arranged in a circle around a central fixation cross (0.23° width × 0.23° height). The stimuli consisted of spiders, butterflies and flowers (see Gerdes *et al.*, 2008, 2009), which were presented in gray scale and all matched for luminance and contrast. Individual stimuli were 2.10° width × 1.72° height. The distance from the fixation cross to the center of each of the six stimuli was 2.67°. Search displays either contained only distractors (spiders *vs* butterflies *vs* flowers) or, among the distractors, there was one discrepant target stimulus from a different category. Overall, seven different arrays (each $n = 90$) were presented: three arrays with spider, butterfly or flower distractors only and four arrays with a spider or butterfly target among flower objects and a flower target among spider or butterfly objects. The targets occurred 15 times at any of the six positions in the matrix. Target positions were randomized over trials. An example of the stimulus array is given in Figure 1A.

The participants were instructed to detect as quickly and accurately as possible targets from a discrepant category in the arrays, by pressing either a 'yes' or 'no' button with the left or the right finger (counterbalanced across participants). There were four practice trials with displays containing a target or not.

A trial was initiated by the appearance of a 500 ms fixation cross preceding each stimulus array to ensure that the participants kept their gaze focused on the central fixation location throughout the experiment. The arrays were presented in random order for each participant with the constraint that no array with a target (either spider, butterfly or flower) or no target (spider, butterfly or flower) was presented on more than four consecutive trials. A trial was terminated by the participants' response, followed by a variable inter-trial interval (ITI) of 1500, 2000 or 2500 ms. Before starting the task, subjects were instructed to avoid eye blinks and excessive body movements during ERP measurement.

Apparatus and data analysis

EEG signals were recorded continuously from 256 electrodes using an Electrical Geodesics (EGI) HydroCel high-density EEG system with NetStation software on a Macintosh computer. The EEG recording was digitized at a rate of 250 Hz, using the vertex sensor (Cz) as recording reference. Scalp impedance for each sensor was kept below 30 kΩ, as recommended by the manufacturer guidelines. All channels were bandpass filtered online from 0.1 to 100 Hz. Stimulus-synchronized epochs were extracted from 100 ms before to 800 ms after picture onset and low-pass filtered (Butterworth filter) at 40 Hz and then submitted to the procedure proposed by Junghöfer *et al.* (2000), as implemented in the EMEGS software provided by Peyk *et al.* (2011). This procedure uses statistical parameters of the data to exclude channels and trials that are contaminated with artifacts. Recording artifacts are first detected using the recording reference (i.e. Cz), and then global artifacts are detected using the average reference, which is used for all analyses. In the present study, electrode site Cz was used as the recording reference, and the average reference was calculated offline, after artifact rejection, and used for all subsequent analyses. Subsequently, distinct sensors from particular trials were removed based on the distribution of their amplitude, standard deviation and gradient. Data at eliminated electrodes were replaced with a statistically weighted spherical spline interpolation from the full channel set (Junghöfer *et al.*, 2000).

For behavioral data, accuracy rates (AR) and response times (RT) of accurate responses were analyzed. Overall, participants responded correctly on 96% of the trials (hits and correct rejections). Response times more than 3 s.d.s above each participant's mean (see Holmes *et al.*, 2009; Weymar *et al.*, 2011) were excluded to eliminate the influence of outliers (1.8% of data). Behavioral data were submitted to repeated measures ANOVAs using the factors target content (spider *vs* butterfly *vs* flower among spiders *vs* flower among butterflies) and group (spider fearful *vs* controls). Extensive analyses of the behavioral data are reported elsewhere (Weymar *et al.*, 2013).

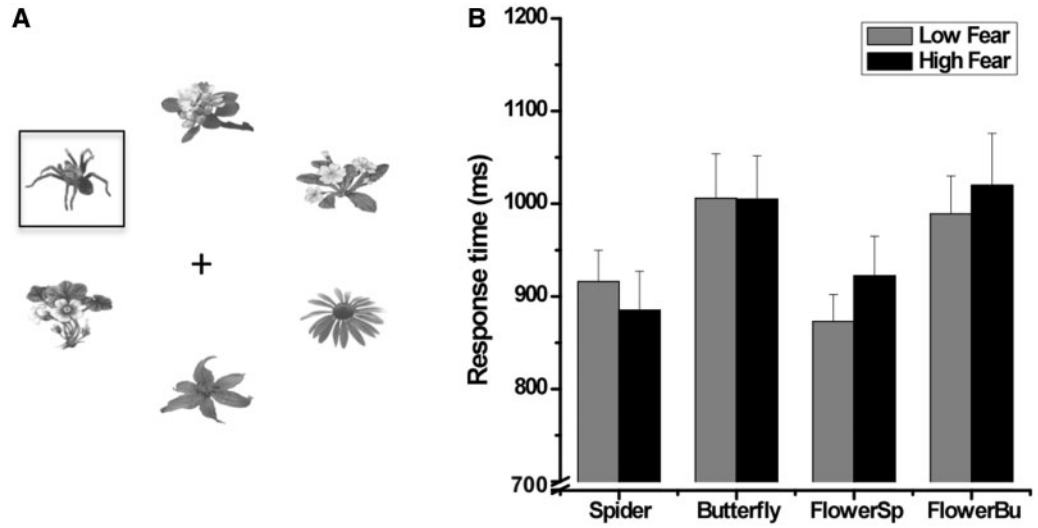

Fig. 1 (**A**) Sample of a search array used in the present study. The square marks the target (spider) among various distractors (flowers). (**B**) Response times for all target conditions [spider targets, butterfly targets, flower targets among spider distractors (FlowerSp) and flower targets among butterfly distractors (FlowerBu)] as a function of group (high fearful *vs* low fearful). Error bars represent standard error of the means (SEM).

ERPs were based on valid trials only (based on hit rate, correct rejection rate and outlier analyses) and were computed for each sensor and participant. Overall, ~18% of the trials were rejected because of artifacts and outliers in response times. These rejected trials were equally distributed across all categories. In consideration of previous research (Pourtois *et al.*, 2004; Stolarova *et al.*, 2006; Kelly *et al.*, 2008) showing an occipito-parietal distribution of the C1 component and based on visual inspection of the waveforms, mean ERP amplitudes were analyzed over posterior electrodes: The C1 was scored on the basis of maximal ERP amplitudes at the EGI sensors 75, 76, 77, 84, 85, 86, 87, 95, 96, 97, 98, 99, 105, 106, 107, 108, 109, 114, 115, 116, 117 (left), and 139, 140, 141, 150, 151, 152, 153, 159, 160, 161, 162, 163, 168, 169, 170, 171, 172, 177, 178, 179, 180 (right), see Figure 2. The timing of the C1 has been established in a plethora of classical studies in visual neuroscience (Spekreijse *et al.*, 1973) and electrophysiology (Clark *et al.*, 1995). We used filter settings similar to Clark *et al.* (1995), leading to similar timing of the early visual evoked potential (VEP) response: The C1, which tends to peak around 50–70 ms and is often preceded by a slope that starts to differ from baseline in the time range before 50 ms, often around 20–40 ms (Parker *et al.*, 1982, Figure 4; Clark *et al.*, 1995, Figure 4; Rauss *et al.* 2009, Figure 3, left). This very early segment may contain carry-over from preparatory or motor processes overlapping and interacting with sensory processing (Vogel and Luck, 2000). Because we were interested in hypervigilance and sustained sensory facilitation, we included this very early interval in our analyses. To test for modulation of the C1 by spatial attention, as well as for content and group effects, a repeated measures ANOVA was conducted including target content (spider *vs* butterfly *vs* flower among spiders *vs* flower among butterflies), target location (left *vs* right relative to fixation) and electrode site (left *vs* right cluster) as within factors and group (high *vs* low spider fear) as between factor. Targets located in the upper and lower left position were merged to one single left location condition ($n = 30$ for each picture), whereas the upper right and lower right target stimuli were averaged for the right location condition ($n = 30$ for each picture), see Figure 1B. Targets presented at the top or bottom mid screen positions did not enter the analyses.

To control for unspecific group differences in ERP amplitude owing to inter-individual differences in signal-to-noise or head geometry/anatomy, we included the P1 amplitude in our analyses. The rationale for this was that any group difference that favors the ERP signal would do so for the C1 and the P1, whereas specific effects should affect one component but not the other. Effects of attention, content and group on the P100 component were tested for the 100–120 ms interval, where the P100 amplitude was maximal. As for the C1, ANOVAs with the factors target content, target location, electrode site and group were carried out for the P100 component over posterior electrodes (see above).

Subsequent analysis of the N100 and N2pc component (see Supplementary Material) showing fear-specific effects in the spider-fearful group are reported elsewhere (Weymar *et al.*, 2013).

For effects involving repeated measures, the Greenhouse–Geisser procedure was used to correct for violations of sphericity.

RESULTS

Behavioral data

Accuracy rates and response times

Accuracy differed as a function of target content, $F(3,138) = 11.79$, $P < 0.001$, $\eta_p 2 = 0.20$. Spider targets were detected better (97%) compared with butterflies [96%, $F(1,46) = 15.17$, $P < 0.001$, $\eta_p 2 = 0.25$] and both flower targets [flower targets among butterflies, 94%, $F(1,46) = 34.36$, $P < 0.001$, $\eta_p 2 = 0.43$, and flower targets among spiders, 96%, $F(1,46) = 6.42$, $P < 0.05$, $\eta_p 2 = 00.12$]. Accuracy did not differ between spider-fearful participants and controls [group: $F(1,46) = 2.33$, $P = 0.13$, $\eta_p 2 = 0.05$]. Owing to the high accuracy rate, data of all target conditions were angular transformed using the arc sine square root transformation. Using this normalization, accuracy was still better for spider targets than for butterfly targets [$F(1,46) = 7.74$, $P < 0.001$, $\eta_p 2 = 0.14$], flower targets among butterflies [$F(1,46) = 367.36$, $P < 0.001$, $\eta_p 2 = 0.44$] and flower targets among spiders [$F(1,46) = 3.79$, $P = 0.06$, $\eta_p 2 = 0.08$]. Accuracy did not differ between both experimental groups [group: $F(1,46) = 2.03$, $P = 0.16$, $\eta_p 2 = 0.04$].

The response times are displayed in Figure 1. A main effect of object content was observed [$F(3,138) = 29.41$, $P < 0.001$, $\eta_p 2 = 0.39$]. Follow-up tests showed that response times for spider targets and flower targets *surrounded* by spider distractors were faster than for butterfly targets [$F(1,46) = 35.84$, $P < 0.001$, $\eta_p 2 = 0.44$, and

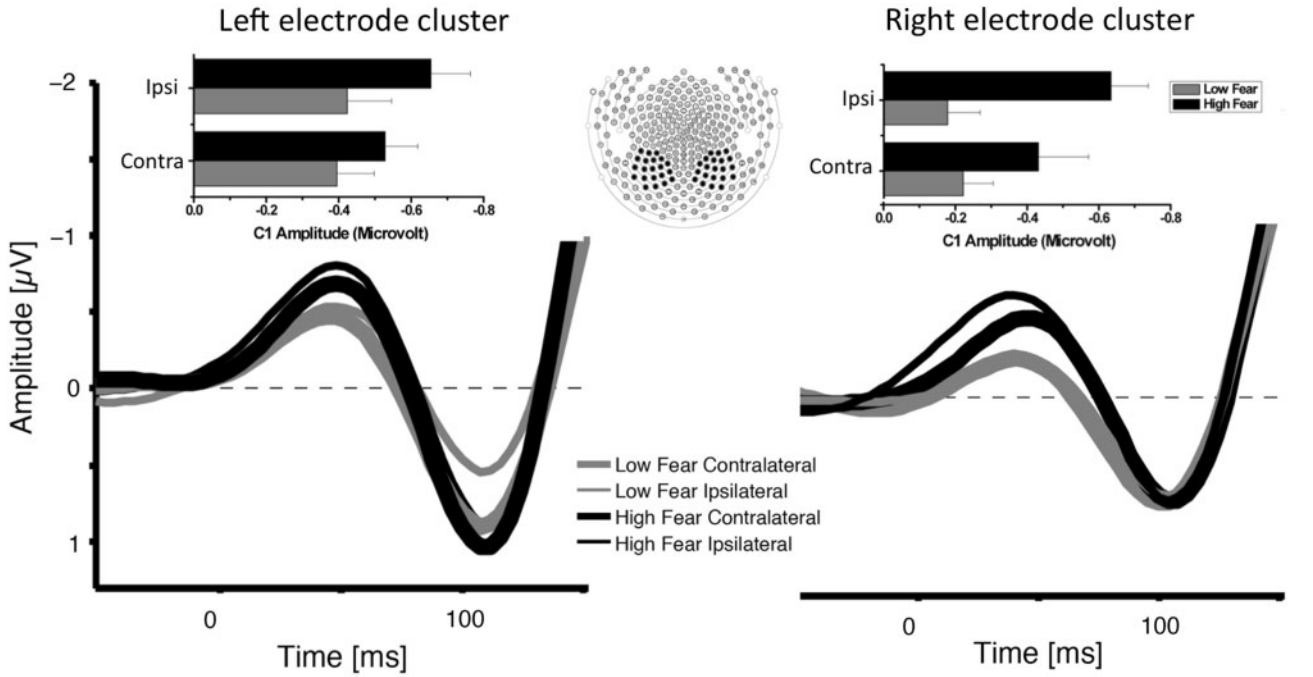

Fig. 2 Hypervigilance in spider-fearful subjects. Grand average ERPs elicited in the 150 ms interval after target onset in response to all targets objects contralateral (thick lines) and ipsilateral (thin lines) to the visual hemifield where the target was presented for spider-fearful (black lines) and control (gray lines) participants. ERPs are averaged across electrodes within posterior sensor clusters (middle section). Insets illustrate the mean ERP amplitude (24–40 ms) for targets presented ipsilateral and contralateral to the visual field at the left and right electrode cluster for both groups.

$F(1,46) = 46.10$, $P < 0.001$, $\eta_p2 = 0.50$] and flower targets among butterflies [$F(1,46) = 30.04$, $P < 0.001$, $\eta_p2 = 0.40$, and $F(1,46) = 56.86$, $P < 0.001$, $\eta_p2 = 0.55$]. Overall, response times did not differ between both groups [$F(1,46) < 1$, $P = 0.83$, $\eta_p2 = 0.00$]. Response times were also analyzed using quartiles of the distributions across conditions and group. Again, shorter response times were observed for trials containing spiders (either as target or background) in both groups, indicating that the pattern of results (Figure 1) did not differ from faster to slower response times.

ERP data

C1

Base and early slope of the C1. Figure 2 shows the grand average ERPs obtained over parieto-occipital sensor clusters contralateral to the target location and ipsilateral to the target location. As can be seen, a C1 component was elicited in response to the target stimuli, starting at ~24 ms after stimulus onset over posterior scalp sites. Overall analysis revealed a trend for an interaction between electrode site and target position [$F(1,46) = 2.95$, $P = 0.09$, $\eta_p2 = 0.06$]. More importantly, significant group effects were observed, showing that spider-fearful participants showed overall a significantly larger C1 amplitude than the control group [$F(1,46) = 6.25$, $P = 0.01$, $\eta_p2 = 0.12$], irrespective of target content, $F(3,138) < 1$, $P = 0.52$, $\eta_p2 = 0.00$, see Figure 2. Moreover, spatial position effects were observed for the C1 component in spider-fearful participants as indicated by a significant interaction between target location, electrode site and group, [$F(1,46) = 3.55$, $P = 0.06$, $\eta_p2 = 0.07$], see Figures 2 and 3. ERP amplitudes were more negative at electrode sites ipsilateral to the position of the target than at contralateral electrodes, target location × electrode site: $F(1,23) = 6.18$, $P = 0.02$, $\eta_p2 = 0.21$, in fearful individuals. In contrast, control individuals showed no electrode × target interaction, $F(1,23) < 1$, $P = 0.91$, $\eta_p2 = 0.00$, but overall larger negative ERP amplitudes over the left compared with right electrodes, electrode site: $F(1,23) = 3.77$, $P = 0.06$, $\eta_p2 = 0.15$.

Peak of the C1. Figure 4 shows the mean ERP amplitude changes for the C1 component as a function of target content and group. In the later time window (40–60 ms), the C1 amplitude continued to be significantly enhanced for the high relative to the low spider-fearful group, $F(1,46) = 8.01$, $P < 0.001$, $\eta_p2 = 0.15$. C1 modulation was not different for the four object targets [content × group, $F(3,138) < 1$, $P = 0.97$, $\eta_p2 = 0.00$]. No spatial position effects were significant for the later time window [target × location: $F(1,46) = 2.70$, $P = 0.11$, $\eta_p2 = 0.06$; target × location × group: $F(1,46) < 1$, $P = 0.33$, $\eta_p2 = 0.02$].

C1 peak amplitudes in response to the non-target conditions (spiders *vs* butterflies *vs* flowers) were also analyzed. Significant group effects were also visible between fearful and non-fearful participants during processing of non-target matrices [$F(1,46) = 5.05$, $P < 0.05$, $\eta_p2 = 0.10$]. A repeated measures ANOVA with the factor target (target *vs* non-target) and group revealed a significant group effect, $F(1,46) = 7.26$, $P = 0.01$, $\eta_p2 = 0.14$, but no significant target effects or interactions [target: $F(1,46) < 1$, $P = 54$, $\eta_p2 = 0.01$; target × group: $F(1,46) < 1$, $P = 0.80$, $\eta_p2 = 0.00$], showing that the enhanced sensory processing in V1 neurons in fearful participants is not specifically related to targets but instead is evident for all presented visual arrays.

Correlations between behavioral measures and C1 amplitude

The detection accuracy was negatively correlated with the amplitude of the C1 (Slope and Peak) in response to all target conditions in spider-fearful individuals (Slope: $r = -0.48$, one-tailed $P < 0.01$; Peak: $r = -0.38$, one-tailed $P < 0.05$) but not in non-fearful individuals (Slope: $r = -0.19$, one-tailed $P = 0.19$; Peak: $r = -0.01$, one-tailed $P = 0.48$), indicating that higher accuracy was associated with larger C1 amplitude in spider-fearful participants.

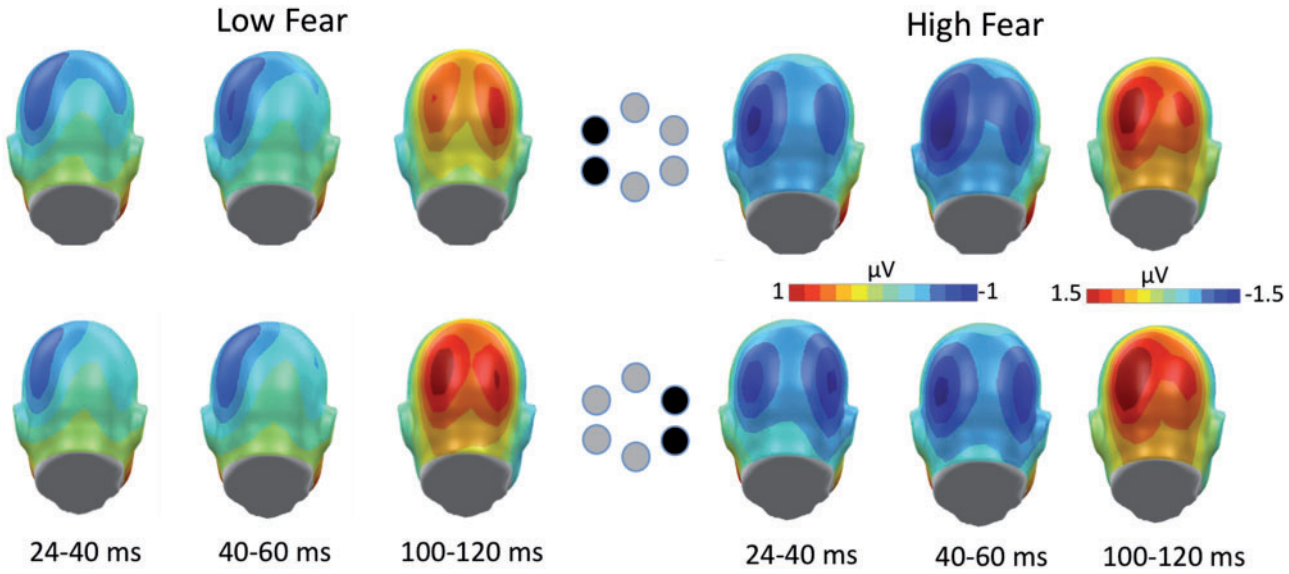

Fig. 3 Illustration of the topographical voltage maps (back views) for all target objects, showing the distribution of C1 negativity in the time interval from 24 to 40 ms and from 40 to 60 ms for control (left) and spider-fearful subjects (right). In addition, P100 topographical maps are shown for both experimental groups for the 100–120 ms time window. Upper panel represents the topography for targets presented in the left visual field, whereas the lower panel represents the neural activity in response to targets presented in the right visual field.

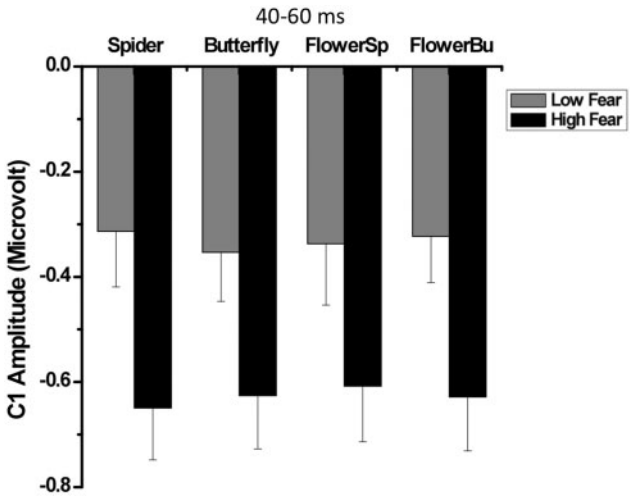

Fig. 4 Magnitude of the C1 amplitude in response to spider targets, butterfly targets, flower targets among spider distractors (FlowerSp) and flower targets among butterfly distractors (FlowerBu) in the 40–60 ms time window for control (gray bars) and spider-fearful participants (black bars). Error bars indicate SEM.

P100

Peak of the P1. The P100 component was peaking in the 100–120 ms time window over posterior scalp sites (see Figures 2 and 3). A main effect of target location indicated larger P1 amplitudes in response to targets presented in the right visual field compared with targets presented in the left visual field, $F(1,46) = 4.28$, $P < 0.05$, $\eta_p 2 = 0.09$. Critically, as opposed to the C1 component, P100 amplitudes did not differ between spider fearful and non-fearful participants, $F(1,46) < 1$, $P = 0.67$, $\eta_p 2 = 0.00$. No effects of content and spatial position were observed for the P100.

DISCUSSION

In the present study, we investigated how fear modulates afferent sensory processing in lower-tier visual cortex. Searching for fear-specific and -unspecific objects in visual space, participants with high fear of specific objects (compared with non-fearful subjects) reliably showed enhanced amplitudes of the C1, the earliest component of visual processing in V1. This C1 modulation was not specifically related to the feared object but was shown for all target stimuli. These results demonstrate a top–down driven, heightened sensitivity to visual stimuli in the environment irrespective of their specific content. Although not discriminating between threat and non-threat stimuli, such sensory hypervigilance in high-fearful individuals appears to be evident already on the afferent pathway to the V1 in a situation in which confrontation with the feared object is expected.

Paralleling a large body of previous work, an enhanced C1 ERP component was detected with a typical widespread distribution over parieto-occipital scalp sites starting at ~40 ms after stimulus onset. The C1 component is known as the first robust visual cortical response, originating in the striate cortex and therefore exclusively reflects V1 activity (e.g. Clark *et al.*, 1995; Di Russo *et al.*, 2002; Kelly *et al.*, 2008). In accordance with the topographical distribution, the timing was also similar to recent visual selective attention and perception studies in humans and animals (Celebrini *et al.*, 1993; Maunsell *et al.*, 1999; Kelly *et al.*, 2008; Rauss *et al.*, 2011; West *et al.*, 2011).

Although the C1 component was long interpreted as robust against cognitive top–down processes, the results of the present study are in line with recent findings that report modulations of the earliest measurable visual response by learning (e.g. Bao *et al.*, 2010), affective meaning (Pourtois *et al.*, 2004; Stolarova *et al.*, 2006) and spatial attention (e.g. Kelly *et al.*, 2008). Two main results were observed in the present study: First, the early part of the C1 component was influenced by the spatial location of visually presented target objects in high-fearful participants only, and second, the C1 was overall significantly enhanced in individuals with high fear of specific objects, indicating an enhanced endogenous vigilance signal in the V1.

Interestingly, the enhanced activity in V1 in the high-fearful group was not fear specific but enhanced for all contents, suggesting general visual hypervigilance for this group. Interestingly, Kolassa *et al.* (2007, Figure 5) found a similar ERP negativity ~50 ms over occipital sensors. Although not explicitly tested, this negativity was enhanced for spider

aficionados and spider phobics compared to controls, corroborating the present findings. Differences in the C1 component cannot be attributed to non-specific electrophysiological between-group differences, because spider-fearful participants were not different from non-anxious participants for the subsequent P100 component[1] (100–120 ms). In contrast to the C1, the P1 was not affected by spatial position or any target content. These findings give rise to the assumption that specific fear modulates the initial V1 afference in an unspecific manner. That is, whenever there is the possibility that a fear-relevant stimulus might occur in the visual field, fearful participants show increased sensitivity to all displayed arrays, which in turn could amplify signals in early visual cortex. Anticipatory priming of V1 neurons has also been found in earlier fMRI studies, where sustained spatial attention activity was found in V1 in the absence of visual stimulation (Kastner *et al.*, 1999; Silver *et al.*, 2007). Recent visual imagery studies also reported increased activity in early visual cortex (Kosslyn and Thompson, 2003; review). Anticipation of feared pictures were associated with enhanced activity in extrastriate visual cortex (Straube *et al.*, 2007), indicating enhanced visual attention while expecting the occurrence of fear-relevant stimuli. In the present study, increased neural activity is already evident in V1 neurons at the earliest cortical stage in high-fearful individuals.

Feedback signals from areas outside visual cortex are assumed to tune V1 neurons in primary visual cortex (e.g. Kastner *et al.*, 1999; Rauss *et al.*, 2011). It is possible that task-related top–down control from frontal and parietal cortex areas, known as part of spatial attention networks (e.g. Mohanty *et al.*, 2009), is able to bias the incoming visual afference in V1. The finding that C1 amplitudes were more pronounced in the high-fear group might indicate enhanced frontal cortex-mediated top–down feedback to facilitate the rapid detection of aversive and fear-specific stimuli. Several speculative accounts are possible to explain such a top–down influence, including predictive coding (Rao and Ballard, 1999; Rauss *et al.*, 2011), where incoming neural signals are matched with internal goals or predictions (prefrontal cortex) of occurring visual stimuli (e.g. the spider) by means of selective attention.

Interestingly, although behavioral performance did not differ between both groups, larger C1 amplitudes were associated with higher accuracy in high-fearful participants, indicating a state of hypervigilance in this group. General hypervigilance in highly fearful individuals (e.g. Gerdes *et al.*, 2008) as shown in the present study is in line with the defense cascade model (Fanselow, 1994; Lang *et al.*, 1997), in which general hypervigilance to all cues in a potentially dangerous context is considered to be the first step of defensive activation followed by selective attention to imminent threat once it occurs and defensive action ('circa-strike') if the threat is becoming more imminent. Once the organism is expecting potential threat, 'pre-encounter' defense is characterized by initial hypervigilance to all stimuli (as already visible in the C1 component), followed by a shift of attention toward the threat cue ('post-encounter' defense) when the threatening stimulus is detected. In line with this model, fear-specific modulations seem to occur at only later cortical stages as reported recently for the N1, N2pc, early posterior negativity (EPN) and late positive potentials (LPP) component (e.g. Kolassa *et al.*, 2005; Leutgeb *et al.*, 2009; Michalowski *et al.*, 2009; Weymar *et al.*, 2013).

Two open questions remain: First, is the enhanced V1 processing in fearful participants driven by general hypervigilance in everyday life or specific to a threat context, where the occurrence of a fearful stimulus is very likely? Because stimuli in the present experiment were shown in a randomized fashion, and trials with spiders occurred already at the beginning of the experiment, we cannot test this hypothesis using the existing data. However, a recent block design study by J.M. Michalowski *et al.* (personal communication) suggests that unspecific hypervigilance only occurs in fearful participants when the feared object is imminent. Investigating the P100, these authors found that in the first block of pictures where no spider was shown, P100 amplitudes were not different for neutral stimuli between spider-fearful participants and controls. However, when the same neutral stimuli were presented in blocks that also included picture of spiders, larger P100 amplitudes were observed for spider-fearful participants than controls, and this difference remained even later in the experiment when no spider was shown, indicating that unspecific hypervigilance in specific phobia occurs in contexts where the probability is high being confronted with their specific threat.

The second question arising from the present electrophysiological findings relates to the extent to which the sensory hypervigilance in spider-fearful participants is reflective of generally higher anxiety or of specific phobia. We collected questionnaire data[2] [Trait scales of the German version of the Spielberger State-Trait Anxiety Inventory (STAI), Laux *et al.*, 1981] and found that C1 amplitudes (40–60 ms) were still larger for spider-fearful individuals than non-fearful controls when both groups were matched based on the STAI trait scores. This suggests that the heightened sensory sensitivity (hypervigilance) in high-fearful individuals to the stimuli, whether fearful or not, is not eminent in individuals with heightened general trait-anxiety but more likely occurs in specific contexts they fear.

Taken together, the present results suggest that high specific fear already modulates the earliest stage of cortical processing in V1. Our findings suggest that incoming new visual information is already biased by threat-unspecific attention in high-fearful individuals.

SUPPLEMENTARY DATA

Supplementary data are available at *SCAN* online.

Conflict of Interest

None declared.

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[1]Enhanced P1 amplitudes were previously found for spider-fearful and (socially) anxious participants relative to controls (e.g. Kolassa *et al.*, 2006, 2007; Michalowski *et al.*, 2009; Wieser *et al.*, 2010) but not in the present study. However, the type of task (visual search) and stimulus material (either presented centrally or peripherally) might lead to study differences. In the present study, spider-fearful individuals showed larger amplitudes in the C1 and N1 (see Weymar *et al.*, 2013) component relative to non-fearful individuals.

[2]To examine the possibility that hypervigilance in spider-fearful participants, as indexed by the enhanced C1 amplitudes, is attributed to general higher anxiety, we collected questionnaire data either before or after the experiment [Trait scales of the German version of the Spielberger State-Trait Anxiety Inventory (STAI), Laux *et al.*, 1981] from 33 participants (16 spider fearful; 17 non-fearful). Trait anxiety was higher in the high-fear group (mean = 49.13) compared with low-fear group (mean = 40.53), $F(1,31) = 12.86$, $P < 0.01$. However, C1 amplitudes (40–60 ms) were still larger for spider-fearful individuals than non-fearful controls [$F(1,18) = 7.88$, $P = 0.01$, $\eta_p2 = 0.30$], when both groups were matched based on the STAI trait scores [spider fearful: Mean = 47.30; non-fearful: mean = 44.50; $F(1,18) = 2.33$, $P = 0.14$, $\eta_p2 = 0.12$]. This suggests that the heightened sensory sensitivity (hypervigilance) in high-fearful individuals to the stimuli, whether fearful or not, is related to the specific fear rather than heightened general anxiety.

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