Unpredictable Fearful Stimuli Disrupt Timing Activities: Evidence from Event-related Potentials

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Abstract

The present study investigated the effect of an imminent fearful stimulus on an ongoing temporal task. Participants judged the duration of a blank temporal interval followed by a fearful or a neutral image. Results showed an underestimation of the duration in the fearful condition relative to the neutral condition, but only when the occurrence of the fearful image was difficult to predict. ERPs results for the blank temporal interval found no effect of the fearful stimulus on the contingent negative variation (CNV) amplitude in the clock stage. However, after the image onset, there was a larger P1 for the fearful relative to the neutral condition. Although this effect was indistinguishable regardless of whether the fearful event could be easily predicted, a late positive potential (LPP) component displayed larger amplitude only for unpredictable fearful stimuli. The time-frequency results showed enhanced delta-theta power (0.5-7.5Hz) for the unpredictable fearful stimuli in the late stage. Importantly, the enhanced delta-theta rhythm correlated negatively with the duration judgments. Together, these results suggest that an unpredictable fearful event might divert more attention away from the counting process in the working memory stage, resulting in missing ticks and temporal underestimation.

Key words: unpredictable fearful stimuli, time perception, late positive potential, delta-theta rhythm

As a negative emotion, fear colors our sense of time in diametrically different ways. On the one hand, a time interval can be overestimated during a state of fear (Chess, Fiesta, Eagleman, & David, 2007; Fayolle, Gil, & Droit-Volet, 2015; Tipples, 2008). For instance, time appears to stand still for people who are involved in a car accident (Arstila, 2012). On the other hand, a time interval can also be underestimated if a fearful event is likely to happen in a near future. For example, worrying about the possibility of a pending electrical stimulation on the skin can resulting in a feeling that the time goes by too quickly (Sarigiannidis, Grillon, Ernst, Roiser, & Robinson, 2020). This compression of a temporal interval only happens when the occurrence of a fearful stimulus is unpredictable or uncertain (Cui, Zhao, Chen, Zheng, & Fu, 2018). In this study, we will mainly focus on this second type of time compression effect.

Although research has identified the links between the time compression effect and anxiety about uncertain future or unpredictable fear (Sarigiannidis et al., 2020; Cui et al., 2018), little is known about the neural mechanisms of this compression effect caused by unpredictable fearful stimuli. To tackle this question, it is necessary to examine the relationship between the neural mechanisms of temporal processing and emotional processing and to identify the stages where emotional processing interferes with temporal processing. Both temporal and emotional processing have been investigated extensively through event-related potentials (ERPs) because the method allows for a high-resolution discrimination among different stages of information processing. To date, however, ERPs research for the two domains has mainly been conducted separately. A major advance in the ERPs research of temporal processing is the discovery of CNV, a component that outputs varying amplitudes as a function of time (Elbert, Ulrich, Rockstroh, & Lutzenberger, 1991; Scheibe, Ullsperger, Sommer, & Heekeren, 2010). This provides neuroscience evidence for a central clock-like timing mechanism proposed in the cognitive literature (Gibbon, 1977; Gibbon, Church, & Meck, 1984; Lake, LaBar, & Meck, 2016), according to which the encoding stage of time perception relies on a pacemaker that emits temporal pulses. The pulses are then summated into an accumulator. The CNV amplitude reflects the output of an accumulator mechanism at this time encoding stage (Casini & Vidal, 2011; Wittmann, 2013). As such, a longer duration is characterized by relatively greater accumulation and hence relatively larger CNV amplitude (Wiener et al., 2012). Following this time encoding stage, also known as clock stage, the accumulated pulses are transferred to working memory, where they are compared to a previously memorized reference duration (Herbst, Chaumon, Penney, & Busch, 2015).

It remains unknown whether the CNV amplitude is modulated by emotional events. However, it is known that emotional stimuli elicit both early and late ERPs components (Codispoti, Ferrari, & Bradley, 2007; Olofsson, Nordin, Sequeira, & Polich, 2008). An early component such as P1 may reflect an automatic attentional bias toward these stimuli. For example, stimuli with a negative valence increases the P1 amplitude (Brosch, Sander, Pourtois, & Scherer, 2008; Codispoti, Ferrari, & Bradley, 2007; Feng, et al., 2014). At a later stage, late positive potential (LPP) seems to reflect the sustained attention to emotion processing and are susceptible to top-down processing influences (Codispoti, Ferrari, & Bradley, 2007; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). Specifically, LPP response is greater to emotional relative to neutral stimuli (Bradley, Hamby, Löw, & Lang, 2007; Hajcak, Dunning, & Foti, 2009; Liao, Zhang, Huang, Xu, & Peng, 2021; Castiajo & Pinheiro, 2021). For example, spiders can enhance LPP amplitudes (Soares et al., 2017). In the time-frequency domain, there is strong evidence that delta oscillations are linked with attentional processes to emotional stimuli (Harmony et al., 1996; Lakatos, Karmos, Mehta, Ulbert, & Schroeder, 2008; Will & Berg, 2007; Zhang et al., 2013). Relative to simple light stimulation, delta responses are higher during perception of grandmother and anonymous faces (Başar et al., 2006, 2007) . Emotional facial expressions such as angry and happy faces elicit higher delta responses than neutral facial expressions (Knyazev et al., 2009). Moreover, threatening pictures can also produce larger theta rhythm response over the posterior cortical regions, indicating the involvement of theta oscillation in mediating motivated attention (Aftanas, Reva, & Makhnev, 2008).

Although prior research has identified these neural correlates of emotional stimuli, it remains unkown how these are related to the neural mechanism of time perception. To understand how the anticipation of a pending emotional event affects judgments of a time interval, we employed a paradigm in which a fearful or a neutral photographic stimulus was presented shortly after the to-be-judged time interval. ERPs responses were taken from two points in each trial (see Figure 1). The first was from the onset of a blank time interval to which the participant had to judge the duration and the second was immediately after the time interval, following the onset of a picture stimulus. Participants were not required to respond to the picture, although they were aware that a picture could be shown after the blank time interval. Following the same manipulation of predictability as Cui et al., trials containing fearful and neutral pictures were mixed in one condition but blocked in another. When the two types of pictures were mixed, the participant was unable to predict which type of stimuli would be presented because the picture in each trial could be either fearful or neutral, determined randomly. However, when the two types of pictures were blocked, the participant was able to tell exactly which type of picture would be shown in a trial because all pictures in one block were always either fearful or neutral.

The design allowed for several predictions. First, according to the temporal processing model, the content of the accumulator indexing the perceived event duration is transferred into a working memory system. The timing of this process is likely to be the point where the blank time interval ends, and the picture is shown. If a fearful picture shown at this point, it could compete with this transfer process for attentional resources, which could explain the “missing ticks from our mental clock” that creates the time compression effect (Coull, Vidal, Nazarian, & Macar, 2004; Macar, Grondin, & Casini, 1994). This would predict an early P1 response to emotional pictures because of their power to elicit attention. The picture stimuli could further elicit sustained attention when it was uncertain whether a fearful or a neutral was shown in a trial. This unpredictability of a fearful event could manifest in a stronger late LPP response, which may reflect the disturbance of the transfer of pulses from the accumulator to working memory system, resulted in an underestimation of time. This prediction could be inferred from prior research, which showed that fearful stimuli compete with task-relevant items for attention and interfere with working memory performance (Curby, Smith, Moerel, & Dyson, 2019; Dolcos & McCarthy, 2006; Kensinger & Corkin, 2003; Zanto & Gazzaley, 2009). For example, when a visual task required the use of working memory, task-irrelevant nociceptive stimuli lose their ability to capture attention and to disrupt the task, compared to the condition in which working memory is not required, suggesting that working memory performance disrupted by the interference from task-irrelevant nociceptive stimuli, can be reduced (Legrain et al., 2011a, b). Moreover, Hajcak et al. (2010) demonstrated a potential opposite effect between working memory load and the LPP amplitude induced by emotional stimuli, where direct stimulation via epidural cortical stimulation (EpCS) of the dorsolateral prefrontal cortex (DLPFC), a brain region implicated in working memory processes, resulted in smaller LPP deflections in response to aversive pictures. Additional evidence also showed LPP amplitude for aversive pictures was modulated by picture content during distraction (Wangelin, Löw, McTeague, Bradley, & Lang, 2011).

It was difficult to predict whether the temporal encoding stage represented by CNV could be affected by emotional processing. Since the CNV for to-be-judged blank interval in our paradigm was recorded before the onset of picture stimuli, the only way for this stage to be influenced would be through a top-down route. Regardless of whether the fearful stimuli were predictable or not, the paradigm allowed participants in both groups (predictable or unpredictable) to know that these images could be presented at some point during the test. On the other hand, the interference with the temporal processing could be mainly due to attentional resources being allocated to the task-irrelevant picture. If so, the early stage of time encoding occurring before the onset of the picture should not be affected by the attentional load at the later stage. As a result, it should show similar amplitude of CNV between fearful and neutral condition. In short, the effect of emotional processing would be more likely to happen when the accumulator accumulates pulse into working memory. A fearful stimulus could receive prioritized access to the limited processing capacity of working memory, resulting in missing ticks and temporal underestimation relative to neutral stimuli. On balance, we expected the time distortion effect to correlate with unpredictable fearful stimuli at this relatively late stage, indexed by the LPP component.

Method

Design

We used a 2 × 2 mixed design. The stimulus type (fearful vs. neutral) was a within-participant factor, and the predictability of the stimulus type (predictable vs. unpredictable) was a between-participant factor.

Participants

A total of 42 healthy right-handed university students took part in this study. Of these, 21 (mean age: 21.15 ± 2.06 years, 1 male) were randomly assigned to the unpredictable group, whilst 21 (mean age: 21.90 ± 2.77 years, 1 male) to the predictable group. All participants gave their written informed consent and were paid 100 yuan (RMB) for their participation. They were all volunteered, reported normal or corrected-to-normal vision, and none had a history of neurological illness. The study was approved by the Ethics Committee of the Institute of Psychology, Chinese Academy of Sciences.

Apparatus and materials

Participants were seated in in a dim, quiet room. The stimuli were presented on a 17-inch CRT monitor with a refresh rate of 100 Hz and a resolution of 1024 × 768 pixels. The viewing distance was set at 60 cm. Stimulus presentation and data collection were implemented by a program written in E-prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA).

Following previous studies (Gelder, Pourtois, Weiskrantz, 2002; Gelder, Morris, & Dolan, 2005), we used sixteen images from the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 2008) in this study. Eight of these were used as fearful (e.g., snakes) and eight as neutral (e.g., dishes) stimuli. The selection of the fearful stimuli was based on Mikels et al. (2005), who used a subset of the IAPS that specifically elicit fear rather than other negative emotions. The mean arousal rating score of IAPS was 6.48 (*SE* = 0.14) for the fearful stimuli and 2.40 (*SE* = 0.17) for the neutral stimuli. Each image was displayed individually on a gray background subtending 13.2° × 11.4° of visual angle.

Procedure

The experiment began with a screening test, where participants estimated the length of a blank interval between a fixation cross and a neutral image that lasted for 300/600/900 ms. Each of the three intervals was presented four times in a random order. Only the participants whose mean reported time for the three temporal intervals increased gradually could take part in the rest of the experiment. All participants passed this screening test.

The rest of the experiment consisted of a training phase and a test phase. During the training phase, participants were told to note the various durations between the offset of a fixation cross and the onset of a neutral image. The purpose was to familiarize the participants with the difference between the durations. Participants were not required to produce any behavioral responses. They were also told not to use counting either vocally or silently as a strategy to judge the durations. We only used neutral stimuli in the training phase to avoid any influence of emotion on time perception. Each trial in both blocks began with a fixation cross randomly varied from 1000 to 1500 ms, followed by a blank interval of variable durations, after which a neutral image was presented for 500 ms. We used two sets of durations between the fixation and the neutral image.The intervals were set to take both round hundreds and non-round hundreds into consideration.The first consisted one of 12 round hundreds durations, ranging from 100 to 1200 ms, with an equal step size of 100 ms. At the same time, in order to familiarize more diversity of time intervals, we used a randomize function of Matlab to produce 10 non-round hundreds intervals that are not exactly 100 from 100-1200 milliseconds to further train the subjects to be familiar with the time of different intervals. So, the second consisted of 10 durations: 150, 280, 360, 440, 550, 640, 760, 850, 970, and 1150 ms. The two sets were used for two blocks of trials, in which the first set was always followed by the second. Each duration was presented only once in each block, with the order being randomized within the block. There were thus a total of 22 trials across the two training blocks.

The test phase followed the training phase. The trial procedure for this phase is illustrated in Figure 1. The two types of trials, labeled as a1 and a2, differed in two respects. First, while type a1 trials showed an image in the third frame, type a2 trials only presented a gray square in this frame. Second, participants were required to make a duration judgment only in the a1 trials. The type a1 trials were used in both participant groups, but the type a2 trials were only used in the group where the occurrence of fearful or neutral stimuli was unpredictable. The reason for including the a2 type trials was to make it difficult to predict whether a picture would be presented in a given trial.

Both a1 and a2 type trials began with a fixation cross at the center of screen. The fixation remained on the screen until participants pressed the ‘F’ key on the keyboard, which turned the screen blank. The blank screen lasted for 610 or 640 ms. The two durations occurred equally in a random fashion. This was then followed by either a fearful or neutral image in an a1 type trial, or by a gray square in an a2 type trial. In both cases the stimulus was shown for 500 ms. This was the end of an a2 type trial. The results of a2 type trial were not analyzed. For the a1 type trial, the stimulus was followed by a response screen, where participants judged the duration of the blank interval by clicking a point on a scale displayed on the screen that ranged from 100 to 1200 ms. The response was self-paced. For both trial types, the inter-trial interval (ITI) lasted between 4800 and 6000 ms to avoid potential inter-trial interference (Shi, Jia, & Mueller, 2012).

There were a total of 144 trials for the unpredictable group, where equal number of trials were assigned to each type of stimuli (i.e., 48 trials for fearful/neutral/gray square). All 144 trials in this condition were fully randomized for each participant. In contrast to this, the fearful and neutral stimuli in the predictable group were presented in separate blocks. This allowed the participants to anticipate these two stimulus types in advance. The order of the two blocks was counterbalanced across the participants in this condition, and the order of trials within each block was randomized for each participant. The condition had 96 trials, where the numbers of neutral and fearful stimulus trials were identical to the other group.

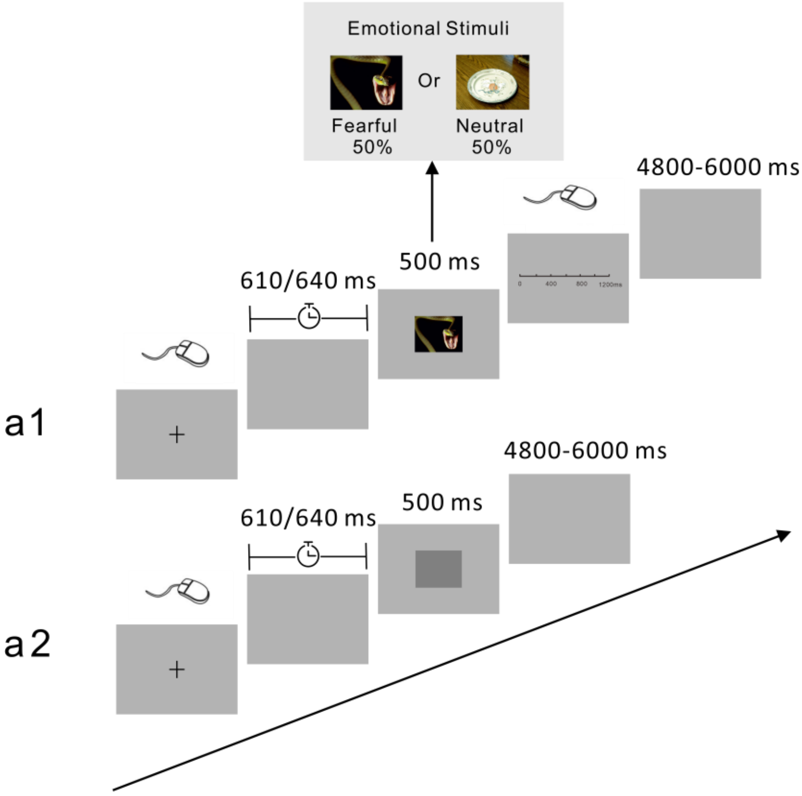

Figure 1. Illustration of experimental procedure. In unpredictable condition, two types of trials (a1 and a2) were presented. The occurrence of a1 and a2 were 2/3 and 1/3, respectively. The ratio of fearful to neutral stimuli was 1:1. In predictable condition, only the a1 trial procedure was used, but the fearful and neutral stimuli were presented in separate blocks.

EEG recording and analysis

EEG data were collected using 64 Ag/AgCl scalp electrodes, which were placed according to the International 10-20 system (Neuroscan Inc., Charlotte, North Carolina, USA). The left mastoid was used as an on-line reference (for recording) and as an off-line (for analysis) algebraic reference to the average of the left and right mastoids. To monitor ocular movements and eye blinks, vertical and horizontal electro-oculographic (EOG) signals were simultaneously recorded using two electrodes, one placed 10 mm below the left eye and the other placed 10 mm from the outer canthus of the left eye. The impedances of all electrodes were kept lower than 5 kΩ. Signals were sampled at 1000 Hz with a 0.05-100 Hz band-pass filter (SynAmps 4.5, Neuroscan, Inc, Charlotte, NC, USA).

EEG data were processed using EEGLAB , an open source toolbox running in the MATLAB environment (Delorme & Makeig, 2004). Recordings were first re-referenced to the average of the left and right mastoids and down-sampled to 500 Hz. Then the continuous EEG data were band-passed at 0.05-40 Hz via a conventional finite impulse response (FIR) filter. EEG signal was segmented into two 1200-ms epochs: one starting 200 ms prior to the time interval and another starting 200 ms prior to presentation of an image, respectively. All epochs were baseline-corrected using a 200 ms pre-stimulus window. The trials containing EEG artifacts were discarded. Furthermore, trials contaminated by eye blinks and movements were corrected using an independent component analysis (ICA) algorithm (Delorme & Makeig, 2004). Single-subject's waveform was subsequently averaged according to different conditions.

For the components correlated with the blank temporal interval in the time encoding stage, we analyzed the CNV amplitudes for neutral and fearful condition. Based on the topography distribution, we mainly focused on the time window 0-600 ms after starting to time in the fronto-central regions. We grouped six electrodes for the analyzing this component (C1, CZ, C2, FC1, FCZ, FC2). As for the components correlated with emotional stimuli, the EEG analyses mainly focused on the amplitudes recorded at occipital-parietal sites according to the scalp topography. The amplitudes of the P1 component were grouped at these electrodes (P1, P2, PZ, POZ) from the single-subject average waveforms, which were further compared. We also compared the amplitudes of LPP in the time window between 200 ms to 600 ms at left parietal region. The LPP was scored by averaging amplitudes from 200 to 600 ms following picture onset, grouped these electrodes (P1, P3, C1, C3, C5, CP1, CP3, CP5, FC1, FC3) according to the scalp topography. To explore lateralization effect, we also compared the difference between the grouped left electrodes (P1, P3, C1, C3, C5, CP1, CP3, CP5, FC1, FC3) and right electrodes (P2, P4, C2, C4, C6, CP2, CP4, CP6, FC2, FC4).

A time-frequency analysis of the EEG signals was also performed, using a windowed Fourier transform (WFT) with a fixed 250-ms Hanning window. Our analysis focused on comparing brain oscillations at lower frequencies (ie, 0.5-40 Hz). Mean amplitude between -400 and -200 ms preceding a stimulus was subtracted from the whole time series for baseline correction. According to the activation pattern and topography distribution, we extracted the delta-theta power (0.5-7.5 Hz) in the time window of LPP at these electrodes (P1, P3, P5, CP1, CP3, CP5, PO3, PO5, PO7 in the left brain, and P2, P4, P6, CP2, CP4, CP6, PO4, PO6, PO8 in the right brain). Mixed factorial analysis of variance (ANOVA) was conducted to compare effects of fearful and neutral stimuli under the two predictability conditions. We also compared the difference between the grouped left electrodes and right electrodes. To further measure the relationship between behavior performance and time-frequency results, correlation indexes were calculated. One variable is the difference between estimated times for the unpredictable fearful and neutral stimuli, while another variable is the difference between delta-theta amplitudes of these two conditions.

Results

Behavioral Results

One participant's data from unpredictable group were excluded because of the reference electrodes fell off of the participant during the experiment. Data from the remaining 41 participants were retained for analysis. ANOVA revealed a significant stimulus type × predictability interaction, $F(1, 39) = 4.79$, $p = 0.04$, $\eta^2_p = 0.11$. Simple effect analysis indicated that the reported time was shorter for the fearful than for the neutral stimuli in the unpredictable condition, $F(1, 39) = 4.59$, $p = 0.04$, $\eta^2_p = 0.11$, whilst no difference between the two stimulus types was found in the predictable condition, $F(1, 39) = 0.94$, $p = 0.34$, $\eta^2_p = 0.02$. No main effect was found for the type of stimuli, $F(1, 39) = 0.65$, $p = 0.43$, $\eta^2_p = 0.02$, or predictability, $F(1, 39) = 0.17$, $p = 0.69$, $\eta^2_p = 0.04$.

ERP Results

ERP components correlated with temporal interval

The results of CNV components are shown in Figure S1. ANOVA showed no significant main effect of stimulus type, $F(1, 39) = 2.04$, $p = 0.16$, $\eta^2_p = 0.05$, or predictability, $F(1, 39) = 0.65$, $p = 0.43$, $\eta^2_p = 0.02$. The interaction between these factors was also not significant, $F(1, 39) = 0.89$, $p = 0.35$, $\eta^2_p = 0.02$.

ERP components correlated with the emotional stimuli

The ERPs waveforms following the onset of image stimuli are shown in Figure 2. We compared the differences between the amplitudes of fearful and neural conditions between 70 to 120 ms for P1 component. The main effect of stimulus type was significant, $F(1, 39) = 31.63$, $p < 0.01$, $\eta^2_p = 0.45$, where the amplitude was stronger for fearful ($M = 1.91$, $SE = 0.30$) than for neutral condition ($M = 1.05$, $SE = 0.33$). There was no effect of predictability, $F(1, 39) = 0.68$, $p = 0.41$, $\eta^2_p = 0.02$, or the interaction between the two factors, $F(1, 39) = 0.46$, $p = 0.50$, $\eta^2_p = 0.01$.

Comparing the LPP amplitudes for fearful and neural conditions between 200 to 600 ms revealed significant main effects of stimulus type, $F(1, 39) = 23.09$, $p < 0.01$, $\eta^2_p = 0.37$, and predictability, $F(1, 39) = 5.80$, $p = 0.02$, $\eta^2_p = 0.13$. The interaction between these two factors was also significant, $F(1, 39) = 4.36$, $p = 0.04$, $\eta^2_p = 0.10$. Simple effect analysis indicated that the amplitude was stronger for the unpredictable fearful than for the predictable fearful images, $F(1, 39) = 7.80$, $p = 0.01$, $\eta^2_p = 0.38$, but no difference between the results of the unpredictable neutral and predictable neutral images, $F(1, 39) = 2.85$, $p = 0.10$, $\eta^2_p = 0.09$. The amplitude of LPP component in the difference wave between fearful and neutral conditions showed no lateralization in unpredictable condition, $t = -0.10$, $p = 0.92$, Cohen's $d = -0.02$.

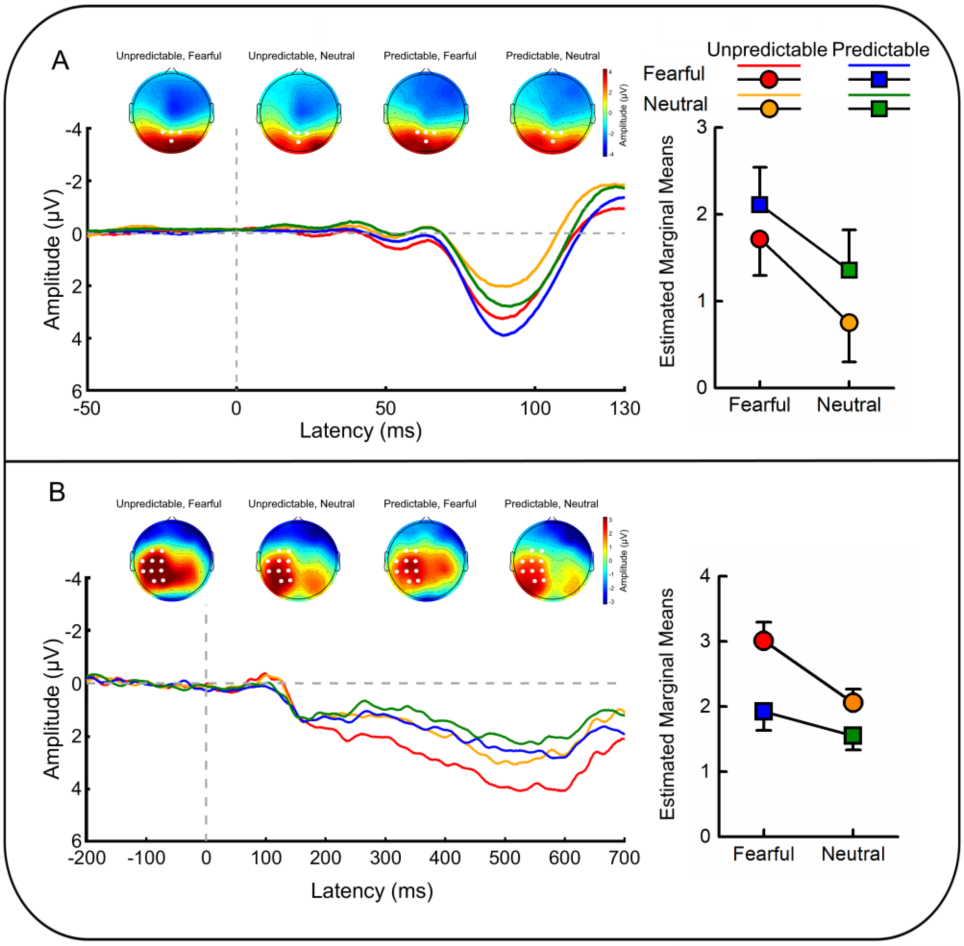

Figure 2. ERP waveform correlated with emotional stimuli. Scalp topography distribution (panel A) and grand averaged waveform of P1, recorded from electrodes of P1, P2, PZ, POZ, for unpredictable and predictable group in fearful and neutral conditions, together with the statistic differences. Scalp topography distribution (panel B) and grand averaged waveform of LPP, recorded from electrodes of P1, P3, C1, C3, C5, CP1, CP3, CP5, FC1, FC3 in the left brain, for unpredictable and predictable group in fearful and neutral conditions, together with the statistic differences.

Delta-theta band rhythm in the time window of LPP component

To study how predictability of fear affected the LPP component, we compared the time frequency results in these conditions (Figure 3). We also assessed whether the results showed a hemisphere difference. For the left brain, the main effect of stimulus type was not significant, $F(1, 39) = 0.21$, $p = 0.65$, $\eta^2_p = 0.01$. Neither was the main effect of predictability significant, $F(1, 39) = 3.36$, $p = 0.08$, $\eta^2_p = 0.08$. However, the interaction between these two factors was significant, $F(1, 39) = 6.10$, $p = 0.02$, $\eta^2_p = 0.14$. Simple effect analysis indicated that the power was stronger for unpredictable fearful than for predictable fearful stimuli, $F(1, 39) = 4.17$, $p = 0.04$, $\eta^2_p = 0.10$; but was not significantly different for unpredictable neutral and predictable neutral stimuli, $F(1, 39) = 2.09$, $p = 0.16$, $\eta^2_p = 0.05$. In addition, we found a negative correlation between the difference in delta-theta rhythm for LPP in the left brain and difference in behavioral results ($r = -0.34$. $p = 0.03$; Figure 4). For the right side of brain, the main effect of stimulus type was not significant, $F(1, 39) = 1.70$, $p = 0.20$, $\eta^2_p = 0.04$. However, the main effect of predictability was significant, $F(1, 39) = 4.61$, $p = 0.04$, $\eta^2_p = 0.11$. So was the interaction between these two factors, $F(1, 39) = 5.56$, $p = 0.02$, $\eta^2_p = 0.13$. Simple effect analysis indicated that the power was stronger for unpredictable fearful than for predictable fearful stimuli, $F(1, 39) = 6.87$, $p = 0.01$, $\eta^2_p = 0.15$; but was not significantly different for unpredictable neutral and for predictable neutral stimuli, $F(1, 39) = 0.54$, $p = 0.47$, $\eta^2_p = 0.01$. The correlation between the difference in delta-theta rhythm in the right brain and difference in behavioral results was also significant ($r = -0.32$. $p = 0.04$; Figure 4). We also compared the power of delta-theta band rhythm of the difference wave between fearful and neutral conditions in left and right sides of brain for the unpredictable condition. Our results showed no lateralization, $t = -0.90$, $p = 0.38$, Cohen's $d = -0.20$.

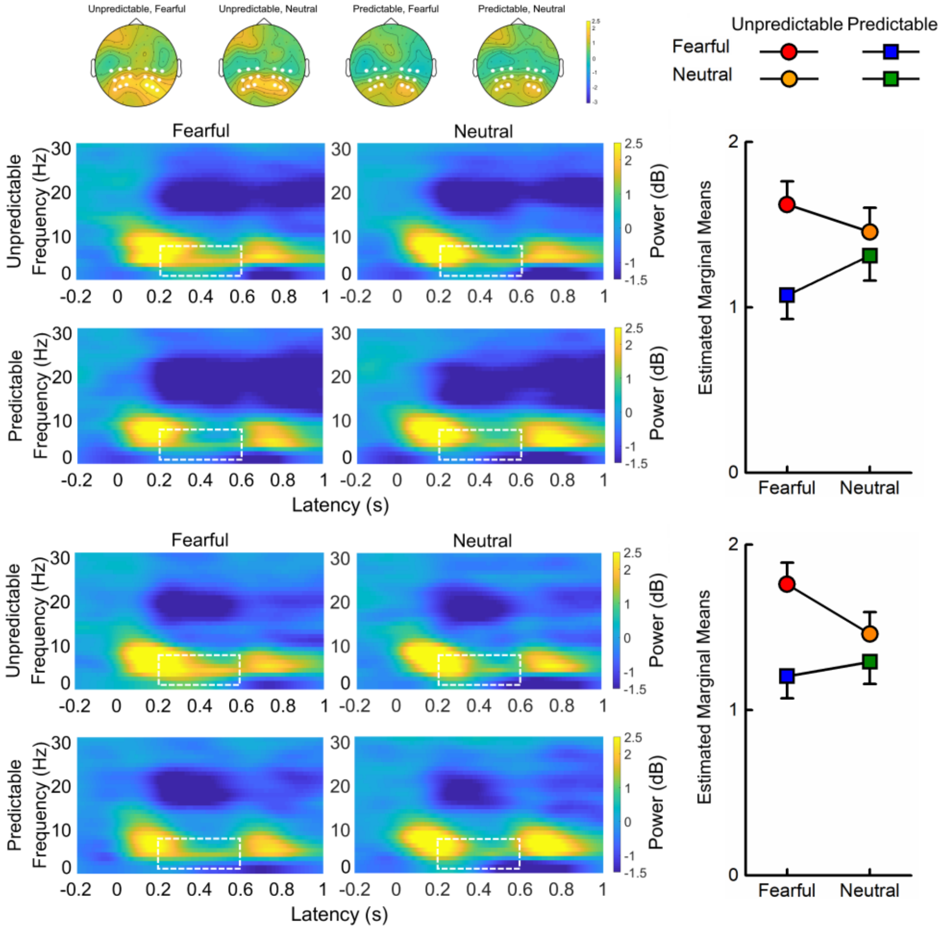

Figure 3. Modulations of EEG oscillations by stimulus type under predictable and unpredictable conditions. Scalp topography distribution (Top) and signals of the group level baseline-corrected oscillations, recorded from electrodes of P1, P3, P5, CP1, CP3, CP5, PO3, PO5, PO7 in the left brain (Middle), and P2, P4, P6, CP2, CP4, CP6, PO4, PO6, PO8 in the right brain (Bottom), for unpredictable and predictable group in fearful and neutral conditions, together with the statistic differences (Right) between the two conditions. The white box represents the delta-theta rhythm (0.5-7.5 Hz) that were analyzed in the time window of 200 to 600 ms.

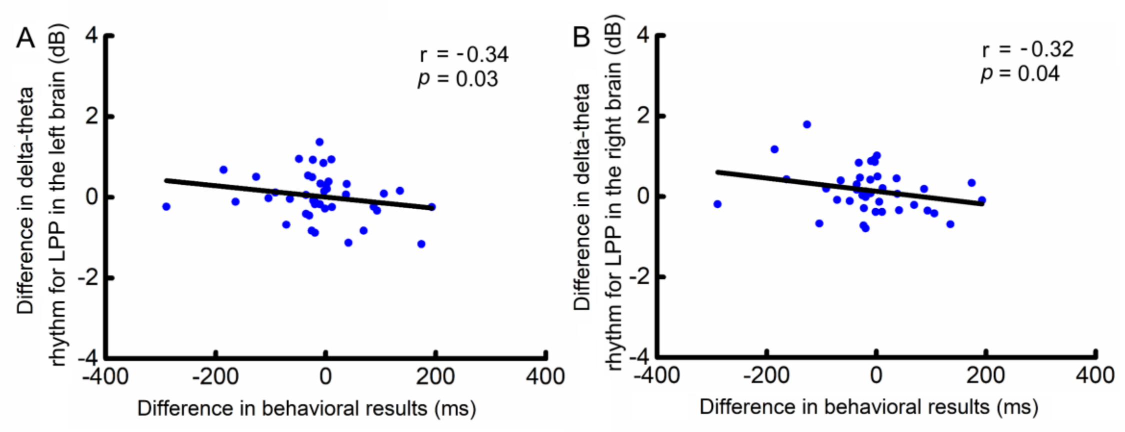

Figure 4. Cross-subject correlation between behavioral performance and delta-theta rhythm in the time window of LPP in the left brain (panel A) and the right brain (panel B).

Discussion

We conducted this ERP study to explore the distortion effect of unexpected fearful stimuli on time perception. The behavioral results showed that the perceived temporal interval was compressed when the fearful stimulus in a trial was not predictable, which replicate a previous behavioral study (Cui, Zhao, Chen, Zheng, & Fu, 2018). ERPs results showed no difference between the CNV amplitudes for the fearful and neutral conditions during the time encoding stage. However, we found greater P1 to the fearful image regardless of whether its occurrence was predictable. Although these earlier ERP components did not echo the behavioral results, in the time window of 200 to 600 ms after the image stimulus onset, the difference between the time-domain ERPs responses to fearful and neutral conditions appeared only when the prediction for the stimulus valence in a trial was not possible. It was only here where the fearful stimuli induced larger LPP amplitude than the neutral condition. The time-frequency results also demonstrated that oscillatory power in delta-theta (0.5-7.5 Hz) band rhythm for unpredictable fearful stimuli was significantly enhanced in the late stage for emotional stimuli. There were significant correlations between the difference in delta-theta band rhythm and difference in behavioral performance in the fearful and neutral image conditions.

The lack of modulation of CNV by the unpredictable fearful stimuli may be due to the fact that the stimuli were presented after the blank interval, at which point the time encoding process would have been completed. Because of this, the only way for the CNV to be affected would be through a top-down route, where the anticipation of a pending fearful stimulus could modulate the CNV response. However, the absence of this effect on the CNV suggests that any top-down influence might not occur at this time encoding stage. Previous study found that the perceived emotional interval in which subjects were asked to estimate the interval of emotional stimuli is positively related to the quantity of attentional resources being dedicated to timekeeper (Buhusi & Meck, 2009). A highly arousal negative emotional stimulus could prompt attentional system to dedicate additional resources to the internal clock processes and let a greater proportion of pulses pass from the pacemaker to the accumulator, which would result in a longer interval representation of the comparison interval. Our results suggest that the knowledge of an immediate future emotional event may not be able to influence or penetrate the clock stage of temporal processing.

For the early stage of emotional processing following the image onset, we found larger amplitude of occipital-parietal P1 for fearful than the neutral pictures in both groups. This is consonant with the prior findings of the ERPs response to negative stimuli (Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004; Müller-Bardorff, et al., 2018). In our study, this early attention bias induced by fearful stimuli was not affected by predictability of stimulus valance, because the P1 effect was found in both participant groups. This also suggests that the P1 component was an indicator of bottom-up attention, which was triggered automatically by the fearful stimuli. However, the early stage of emotional processing seems to have little impact on temporal processing, because the P1 effect was not correlated with the time compression effect.

Our results suggest that the time compression effect of unpredictable fearful event occurs at a late processing stage after image stimuli presented, signaled by a stronger amplitude of LPP for unpredictable fearful stimuli. Previous studies did also report enhanced LPP amplitude elicited by negative stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Dillon, Cooper, Grent, Woldorff, & LaBar, 2006; Hajcak, Dunning, & Foti, 2007; Liu, Huang, McGinnis-Deweese, Keil, & Ding, 2012; Schindler & Straube, 2020; Schupp, et al., 2000; Weinberg, Hilgard, Bartholow, & Hajcak, 2012), or high arousal stimuli (Schup & Junghöfereta, 2004). However, our result showed for the first time that LPP is not only elicited by such negative stimuli but also by the interaction between anticipation of these stimuli and time perception. As the fearful stimuli in this study were presented at the end of blank temporal interval, the LPP effect might reflect the cognitive process at a stage of time perception when the accumulator accumulates pulse in the working memory. Perhaps when the perceived duration of an event is transferred transiently into working memory, a strong negative stimulus can interfere with the ongoing timing activities. Unpredictable fearful stimuli, for example, might have the opportunity to gain priority access to cognitive processing. This could consume the limited resources in the working memory and consequently interfere with temporal processing, resulting in an underestimation of time in the task.

In addition to LPP, the effect of unpredictable fearful stimuli was also indexed by delta-theta rhythm. It is only when the emotional stimuli were exposed, did the effect of emotion start to show in the ERP components. This may be the point where the content of the accumulator consisting the accumulated pulses is transferred into the working memory. Under the condition where the occurrence of a fearful picture in a trial was unpredictable, its exposure might have gained prioritized access to the limited cognitive capacity in the working memory and consequently interfered with the late stage of temporal processing. Consistent with previous studies (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000), delta-theta rhythm results seemed to reflect a disruption of time perception by emotion processing. Prior research has identified a connection between emotional stimuli (e.g., facial expressions, IAPS pictures, etc.) and sustained attention as well as how sustained attention could be manifested in delta-theta oscillations (Balconi & Pozzoli, 2009; Balconi et al., 2009; Başar, Özgören, Öniz, Schmiedt, & Başar-Eroğlu, 2007; Harmony, et al., 1996; Klados et al. 2009; Knyazev, Slobodskoj-Plusnin, & Bocharov, 2009; Lakatos, Karmos, Mehta, Ulbert, & Schroeder, 2008; Will & Berg, 2007; Zhang, et al., 2013). Our results showed that these delta-theta rhythm at the parietal sites were elicited for the unpredictable fearful stimuli, which may reflect more attentional resources being attracted by these stimuli. The negative correlation between delta-theta rhythm and the reported time found in our analysis supports this explanation. These results echoed with a previous study which also found that a negative relationship between delta-theta amplitude and compressed time (Zhao et al., 2014). Furthermore, a recent study has found that low-frequency (e.g., delta) rTMS applied in the parietal fissure, corresponding to the Pz electrode reference according to the 10–20 system of the electroencephalography resulted in an underestimation of 1-s time interval compared to the sham condition (Manaia et al., 2019). This could be due to the effect of parietal inhibition on the attentional level and working memory functions during time estimation. In addition, neurons in the posterior parietal cortex (area LIP) was also found represented elapsed time relative to a remembered duration (Leon & Shadlen, 2003). Based on the literature between delta-theta rhythm and working memory perfomance, our study support that as the result of prioritized access by this emotion processing to the limited capacity of working memory, the temporal processing task could be disrupted resulting in missing ticks and temporal underestimation. It is worth noting that our results showed no hemisphere dominance for both LPP and delta-theta rhythm underlying the time compression effect.

The present study has some limitations, among them the size of the sample is a little small. Even though we found no effect of stimuli on the clock stage (i.e., CNV), further studies are needed to clarify the issue. Another limitation is we relied on the results of the two between-participant groups to infer the disruptive effect of unpredictable fear on time perception. Further research should investigate the effect of predictability in the same experiment.

In summary, the current study testified that unpredictable fearful stimuli could compress subjective time. This effect happens at a late processing stage after the onset of an unpredictable event. Unpredictable fearful stimuli might have better opportunity to gain prioritized access to cognitive processing and consequently interfere with the working memory process. It was the first attempt to characterize the electro-physiological mechanism underlying the phenomenon whereby unpredictable fearful stimuli disrupt time perception.

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