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Article

Habitual Use of Reappraisal to Regulate Emotions Is Associated With Decreased Amplitude of the Late Positive Potential (LPP) Elicited by Threatening Pictures

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Abstract: In contrast to our knowledge about instructed emotion regulation, rather little is known about the effects of habitual (or "spontaneous") emotion regulation on neural processing. We analyzed the relationship between everyday use of cognitive reappraisal (measured by the Emotion Regulation Questionnaire, ERQ-R), and the amplitude of the late positive potential (LPP), which is sensitive to down-regulation of negative emotions via reappraisal. Participants viewed a series of neutral and threatening images, and rated them for level of threat. We found increased LPP amplitude for threatening compared to neutral pictures between 500 and 1,500 ms. Crucially, we found smaller LPP amplitudes to threatening versus neutral pictures for participants who used reappraisal more often in everyday life. This relationship between LPP amplitude and the ERQ-R was observed in the 1,000–1,500 ms interval of the LPP, over right centro-parietal electrodes. The current findings indicate that habitual tendency to use reappraisal is associated with reduced amplitude of the LPP in response to threatening pictures, in the absence of any explicit instruction to regulate emotions.

Keywords: emotion, emotion regulation, late positive potential (LPP), spontaneous reappraisal

Emotions are vital for ensuring adaptive responses to events and situations that require immediate action, such as the sudden appearance of a threatening person or animal in the vicinity. However in certain situations, emotional responses may be maladaptive, for example, in the case of an imagined threat or danger. The ability to appropriately control and regulate one's emotional reactions is therefore of great importance for healthy psychological and social functioning (Gross, 2002). Based on the process model of emotion regulation (Gross, 1998, 2015), cognitive reappraisal is an antecedent-focused regulation strategy that aims to alter emotional responses before they become activated in full, by reinterpreting the meaning or self-relevance of a situation or event. Cognitive reappraisal is an effective strategy for regulating affective responses which has been shown to successfully decrease subjective negative emotional experience (e.g., Ray, McRae, Ochsner, & Gross, 2010), and is a core aspect of psychotherapeutic techniques such as cognitive behavioral therapy (CBT).

Cognitive reappraisal can be implemented in two conceptually distinct ways: either under instruction or spontaneously. The vast majority of research studies into cognitive reappraisal have employed an instructed approach, where participants are given explicit instructions about how and/or when to employ the strategy of reappraisal, and participants are usually given an opportunity to practice applying the strategy before the experimental task begins. The advantage of the instructed approach is that the causal effects of the emotion regulation strategy can be readily assessed, and this approach has been successful in providing evidence about the behavioral benefits and neural processes related to reappraisal (e.g., Goldin, McRae, Ramel, & Gross, 2008; Kim & Hamann, 2007; McRae et al., 2010; for review, see Cutuli, 2014).

However, emotion regulation under experimentally instructed conditions is rather artificial compared to the typical mode of employment of emotion regulation strategies outside the laboratory. In everyday life it is frequently

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necessary to regulate and modulate the strength and/or duration of emotions in the absence of specific instructions to do so; in other words, emotions are regulated *spontaneously* (also known as "habitual emotion regulation" Gyurak, Gross, & Etkin, 2011). Moreover, it is known that individuals differ in the extent to which they spontaneously employ emotion regulation strategies; more frequent use of cognitive reappraisal in everyday life (i.e., under non-instructed conditions) has been shown to be associated with a number of favorable psychological outcomes such as lower levels of negative affect, greater interpersonal functioning, and enhanced psychological and physical well-being (Garnefski, Kraaij, & Spinhoven, 2001; Gross & John, 2003; for review see Cutuli, 2014).

It is also known that the dispositional tendency to use emotion regulation strategies is associated with the strength of neural responses elicited by emotionally valenced stimuli, as measured by functional magnetic resonance imaging (fMRI; for review, see Cutuli, 2014). For example, decreased activity in the amygdala, as measured by fMRI, was observed following presentation of unpleasant facial expressions, in participants who reported more frequent use of cognitive reappraisal in everyday life (Drabant, McRae, Manuck, Hariri, & Gross, 2009). However, very little is known about the influence of habitual emotion regulation strategies under non-instructed viewing conditions on electrophysiological measures of affective processing, which can provide precise temporal information concerning the different stages of processing of an emotional stimulus.

Using event-related potentials (ERPs), electrophysiological studies of instructed cognitive reappraisal have commonly focused on modulation of the late positive potential (LPP), a sustained positive deflection in the event-related potential elicited by affective cues, with a peak latency of around 500 ms over centro-parietal cortex (Hajcak, Weinberg, MacNamara, & Foti, 2012; Paul, Simon, Kniesche, Kathmann, & Endrass, 2013; Thiruchselvam, Blechert, Sheppes, Rydstrom, & Gross, 2011) and commonly lasting up to 1,500 ms or beyond (Hajcak & Nieuwenhuis, 2006; Weinberg & Hajcak, 2011). The LPP is thought to reflect extensive processing related to stimulus salience (for reviews, see Hajcak, ManNamara, & Olvet, 2010; Hajcak et al., 2012; Olofsson, Nordin, Sequeira, & Polich, 2008), and is commonly assessed in early (e.g., 500–1,000 ms) and later (e.g., > 1,000 ms) time-windows (e.g., Hajcak & Dennis, 2009; Sarlo, Übel, Leutgeb, & Schienle, 2013). The early portion of the LPP is thought to index enhanced attention to motivationally relevant stimuli, whereas the later portion may reflect deeper processing and the appraisal of stimulus meaning (Hajcak et al., 2010, 2012; MacNamara, Foti, & Hajcak, 2009). The LPP has been shown to be sensitive to regulation of emotion via cognitive reappraisal, with studies typically showing decreased amplitude of the LPP in response to negative pictures when participants are instructed to reappraise the meaning of the images (e.g., Hajcak & Nieuwenhuis, 2006; Paul et al., 2013; Thiruchselvam et al., 2011; although see Baur, Conzelmann, Wieser, & Pauli, 2015).

We are aware of only one study that has investigated the effects of individual differences in habitual emotion regulation on electrophysiological indices of affective processing in the context of passive viewing of pictures (i.e., in the absence of explicit instructions to regulate). In this study, Zhang and Zhou (2014) investigated modulation of the LPP in relation to individual differences in automatic emotion regulation, which was defined as the goal-driven regulation of affect in the absence of conscious decision or deliberate control. Participants were divided into two groups, based on their scores on the emotion-regulation Implicit Association Test (Mauss, Evers, Wilhelm, & Gross, 2006): One group consisted of participants who tended to automatically control their emotions, and the other group consisted of participants who tended to automatically express their emotions. The ERP data showed that participants in the automatic emotion control group had reduced right-sided posterior LPP amplitude differences between high and low arousal emotional pictures, compared to the group with automatic emotion express tendencies. While Zhang and Zhou's (2014) study provided evidence that individual differences in emotion regulation tendencies modulated the LPP, it was not clear from the study which specific emotion regulation technique the participants habitually used, for example, participants could have used repression, or distraction, as automatic techniques to control emotions. In other words, their study could not shed light on the specific effects of habitual cognitive reappraisal on the LPP.

The goal of the current study was therefore to use event-related potentials (ERPs) to test whether, in the absence of explicit instructions to regulate emotions, the habitual tendency to use cognitive reappraisal was associated with the strength of cortical responses to threatening pictures, as measured by the LPP. Participants' habitual use of cognitive reappraisal was assessed using the reappraisal scale of the Emotion Regulation Questionnaire (ERQ-R; Gross & John, 2003). All valenced cues in the current study belonged to a single emotional category (threat) that has high intrinsic motivational relevance. We expected amplitude differences in the early posterior negativity (EPN) and the LPP components, between threatening versus neutral images, in line with previous research (Hajcak et al., 2010; Lang & Bradley, 2010; Van Strien, Eijlers, Franken, & Huijding, 2014; Van Strien, Franken, & Huijding, 2009). Participants' subjective ratings of the threat value of the presented stimuli were collected after picture offset. Participants' trait anxiety levels were assessed via self-report to control for emotional reactivity (Kashdan, 2002), and we controlled for the use of expressive suppression to ensure that the results would not be due to individual differences in regulating emotion via a different regulation strategy. We expected to observe a decreased amplitude of the LPP in response to threatening pictures in participants who more frequently used cognitive reappraisal in their daily lives. Secondly, following Zhang and Zhou (2014), we expected to observe cortical asymmetry in the association between the LPP and the self-reported use of cognitive reappraisal.

Methods

Participants

Sixteen participants (11 males and 5 females) voluntarily took part in the experiment. Mean age was 29.0 years (*SD* = 7.9). All participants had normal or corrected-to-normal vision, and 15 participants were right-handed. All participants gave written informed consent to the study. The experiment was approved by the Liverpool Hope Psychology Ethics Committee.

Stimuli

Thirty neutral and 30 threatening images were selected on the basis of valence and arousal norms from the International Affective Picture System[1] (IAPS; Lang, Bradley, & Cuthbert, 2008). The threat pictures depicted actual or potential physical threat or harm and were rated low on pleasure (mean = 2.28, *SD* = 0.75) and high on arousal (mean = 6.41, *SD* = 0.62) according to the standardized affective rating system (Lang et al., 2008) and included scenes of physical attacks, dead bodies, and accidents. Neutral pictures were rated near the midpoint of the valence scale (mean = 5.19, *SD* = 0.55) and low on arousal (mean = 3.52, *SD* = 0.62) and included pictures of people and objects, landscapes, and animals.

The freqspat.m Matlab function from Delplanque, N'diaye, Scherer, and Grandjean (2007) was used to confirm that the two picture categories did not differ in spatial frequencies (all *p*s > .611). The mean and standard deviation luminance was equalized for all 60 images using the lumMatch.m function from the SHINE toolbox for Matlab (Willenbockel et al., 2010).

Questionnaires

The 10-item Emotion Regulation Questionnaire (ERQ; Gross & John, 2003) was used to measure emotion regulation strategy. The ERQ uses ratings from 1 (= *strongly disagree*) to 7 (= *strongly agree*) and contains six items measuring individual differences in use of cognitive reappraisal (e.g., "When I'm faced with a stressful situation, I make myself think about it in a way that helps me stay calm"), and four items related to use of expressive suppression (e.g., "I control my emotions by not expressing them"). Participants also completed the 20-item trait version of the State-Trait Anxiety Questionnaire (STAI; Spielberger, 1968).

Procedure

Participants completed the ERQ and the trait STAI prior to the Electroencephalograph (EEG) experiment. For the EEG experiment, participants were seated at a distance of 60 cm from a computer screen. Each trial began with a central fixation cross lasting 1,500 ms, immediately followed by presentation of either a neutral or threatening image for 1,500 ms (e.g., Mogg, Bradley, Miles, & Dixon, 2004). Next, a Likert scale appeared in the center of the screen for participants to rate the preceding image for threat on a 1–9 scale (1 = *not at all threatening*; 9 = *extremely threatening*). Participants were instructed at the start of the experiment that threat was defined as "the degree of physical harm or danger to others which the picture depicts and/or the degree of uneasiness or fear which the picture makes you feel" (Mogg et al., 2000). After the participant had entered a number between 1 and 9, a blank screen appeared for 1,000 ms, and then the next trial began. Q2

Prior to the main experiment, participants completed a practice block of six trials, with visual images that were not included in the main experiment. In the main experiment 180 images were displayed (90 threatening images, 90 neutral images), in three blocks of 60 trials. The order of trials was randomized. The experiment was controlled using E-Prime 2.0.

EEG Data Acquisition and Preprocessing

EEG data was recorded from 64 scalp electrodes using an Active Two amplifier system (BioSemi, Amsterdam, The Netherlands). Electrodes were placed according to the extended 10–20 system (Nuwer et al., 1998). Four additional

[1] The threatening IAPS pictures were: 1052, 1120, 1300, 1932, 3010, 3015, 3060, 3064, 3068, 3069, 3168, 3530, 6230, 6244, 6260, 6312, 6313, 9040, 9042, 9301, 9325, 9405, 9410, 9413, 9433, 9584, 9630, 9635.1, 9901, and 9940. The neutral IAPS pictures were: 1350, 1121, 1670, 1947, 2104, 2107, 2214, 2220, 2305, 2377, 2382, 2383, 2393, 2396, 2397, 2400, 2411, 2441, 2484, 2489, 2500, 2595, 7009, 7025, 7026, 7190, 7513, 7547, 7920, and 7950.

leads were placed above and below the left eye and on the outer canthi of the left and right eyes, to record the vertical and horizontal electrooculogram (EOG; VEOG and HEOG, respectively). Electroencephalograph (EEG) signals from all channels were acquired with respect to the common mode sense (CMS) electrode at a sampling rate of 512 Hz, and were digitally filtered (second-order zero-phase-lag bandpass filter, 0.1–30 Hz). The continuous EEG was divided into epochs offline, beginning 1,500 ms prior to stimulus onset and ending 1,500 ms after stimulus onset. EEG artifacts were rejected using the spontaneous coronary artery dissection (SCADS) procedure with standard parameters (Junghöfer, Elbert, Tucker, & Rockstroh, 2000). This procedure first detected individual channel artifacts, then transformed the data to the average reference and then identified global artifacts. Epochs that contained more than 10 unreliable electrodes were excluded from analysis on the basis of the distribution of their amplitude, standard deviation, and gradient. For the remaining epochs, data from artifact-contaminated sensors was replaced by a statistically weighted spherical interpolation using the complete electrode set. With respect to the spatial distribution of the approximated electrodes, it was ensured that the rejected channels were not localized within one region of the scalp, as this would make interpolation for this area unreliable. Therefore the standard deviation of the spherical splines used for approximation was computed for each epoch and epochs that represented outliers from this distribution were rejected. Across all participants and all conditions the procedure rejected an average of 36.9% of epochs as artifacts [there was no difference in rejection rate per condition, $t(15) = .284$, $p = .780$].

Event-Related Potentials (ERPs)

ERPs were averaged separately for each stimulus condition (threat and neutral), to produce two ERPs per participant. ERP amplitudes were aligned to a 100 ms pre-stimulus baseline period. The early posterior negativity (EPN) was derived from mean activity in the 200–300 ms time-window at left (O1, PO3, PO7) and right (O2, PO4, PO8) lateral occipital electrode locations (Van Strien et al., 2009, 2014).

The late positive potential (LPP) was maximal at around 550 ms over centro-parietal electrodes, and lasted for the duration of the stimulus (i.e., 1,500 ms), consistent with results from previous studies (e.g., MacNamara & Hajcak, 2009). Analysis of the LPP was conducted during two time intervals (500–1,000, and 1,000–1,500 ms, following stimulus onset), in close agreement with a number of previous studies (e.g., Hajcak & Dennis, 2009; Sarlo et al., 2013; Solomon, DeCicco, & Denis, 2012).

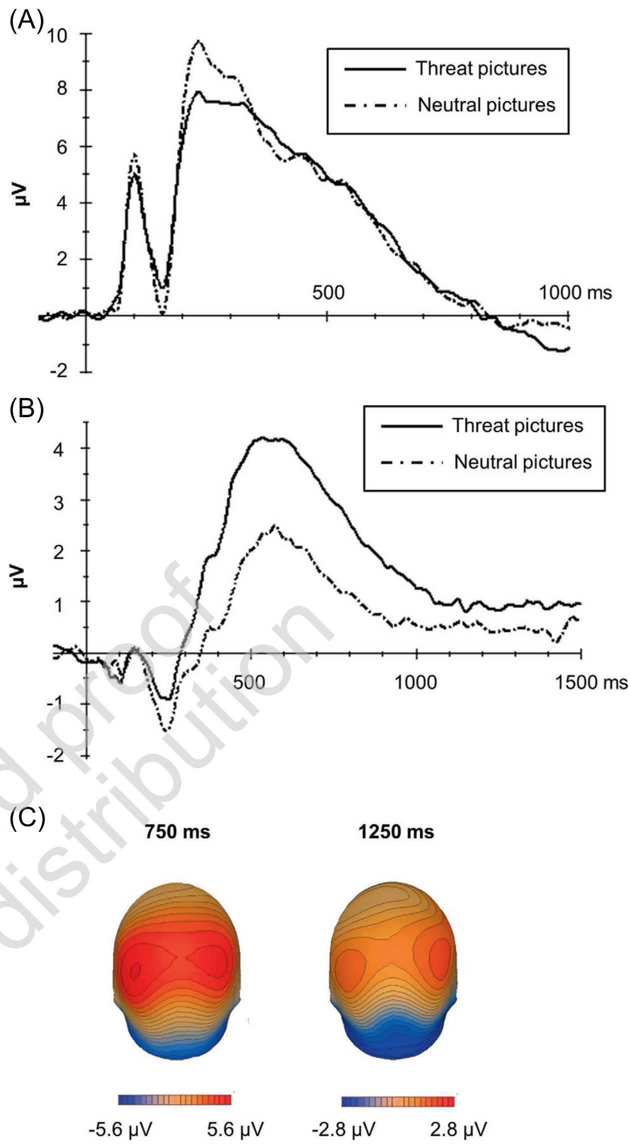

Figure 1. ERP plots of the early posterior negativity (EPN) and late positive potential (LPP). (A) Grand-averaged ERPs for the threat (solid line) and neutral (dashed line) conditions, averaged over occipito-parietal locations, show an EPN between 200 and 300 ms after stimulus onset, where the waveform for the threat condition is more negative than the neutral condition. (B) The LPP, averaged across left and right centro-parietal electrode clusters, for the threat (solid line) and neutral (dashed line) conditions. The LPP has a peak latency of around 550 ms after stimulus onset and is evident for the whole duration of the stimulus presentation (i.e., 1,500 ms). (C) Topographic maps (back view) of the earlier (left) and later (right) late positive potential (LPP).

In the 500–1,000 ms time-window, the LPP displayed a broad bilateral distribution over posterior electrode sites (Figure 1C). A cluster of three electrodes was selected based on the sensors showing maximum LPP amplitude (P1, P3, and PO3). Equivalent electrodes in the right hemisphere were selected (P2, P4, and PO4). In the 1,000–1,500 ms time-window, the LPP showed a bilateral distribution over slightly more superiorly located centro-parietal sensor positions (Figure 1C). A cluster of three electrodes was selected based on the sensors showing maximum LPP amplitude within this time-window (CP2, CP4, and C4). Equivalent electrodes in the left hemisphere were selected (CP1, CP3, and C3). These electrode locations are very similar to those reported in previous investigations of the LPP (e.g., Gerdes et al., 2013; Leleu et al., 2015; MacNamara & Hajcak, 2009). The mean amplitudes for each electrode cluster within each time-window were submitted to a repeated-measures analysis of variance (ANOVA) with the factors Condition (threat and neutral) and Scalp Laterality (left and right).

Results

Participant Characteristics and Threat Ratings

There was a marginally significant negative correlation between dispositional cognitive reappraisal and trait anxiety ($r = -.457$, $p = .075$). Confirming the experimental design, participants rated the threatening pictures as more threatening (mean = 6.84, SD = 1.11) than the neutral pictures (mean = 1.56, SD = 0.51; $t(15) = 19.217$, $p < .001$). A Pearson's correlation analysis revealed no relationship between cognitive reappraisal and threat ratings ($r = .343$, $p = .193$).

Event-Related Potentials

Early Posterior Negativity (EPN)

To assess the effectiveness of the threatening images to elicit affective responses, we analyzed the EPN, which is known to be related to emotional processing (e.g., Van Strien et al., 2009, 2014). Between 200 and 300 ms ERPs evoked by unpleasant pictures showed a relative negative potential difference over occipito-parietal sites, compared to neutral pictures (see Figure 1A), characteristic of the EPN component (Van Strien et al., 2009, 2014). Mean amplitudes in the 200–300 ms interval were submitted to a repeated-measures ANOVA with the factors Condition (threat and neutral) and Scalp Laterality (left and right). This analysis revealed a significant main effect of Condition, $F(1, 15) = 8.99$, $p = .009$, where amplitudes to threatening images (mean = 7.33, SD = 3.81 μV) were less positive than amplitudes to neutral images, (mean = 8.58, SD = 3.71 μV). There was also a significant interaction between Condition and Scalp Laterality, $F(1, 15) = 7.20$, $p = .017$. Follow-up analyses revealed that the EPN was less positive for threatening than for neutral pictures in the left cluster, $t(15) = 3.411$, $p = .004$, but the effect was only marginally significant in the right cluster, $t(15) = 2.113$, $p = .052$.

Late Positive Potential (LPP)

Grand-averaged ERP waveforms displayed a late positive potential (LPP), consisting of a sustained positive deflection with a peak amplitude occurring at around 500 ms over posterior electrodes (Figures 1B and 1C). Mean amplitudes in the 500–1,000 ms and the 1,000–1,500 ms intervals were submitted to separate repeated-measures ANOVAs with the factors Condition (threat and neutral) and Scalp Laterality (left cluster and right cluster). Between 500 and 1,000 ms the analysis revealed a significant main effect of Condition, $F(1, 15) = 23.6$, $p < .001$, where amplitudes were higher in the threat condition (mean = 3.86, SD = 2.04 μV) compared to the neutral condition (mean = 2.40, SD = 1.82 μV). There was no main effect of Scalp Laterality ($p = .404$) and no Condition by Scalp Laterality interaction ($p = .973$). Between 1,000 and 1,500 ms, there was a significant main effect of Condition, $F(1, 15) = 7.20$, $p = .017$, where amplitudes were higher in the threat condition (mean = .97, SD = 1.24 μV) compared to the neutral condition (mean = .48, SD = 1.13 μV). There was no main effect of Scalp Laterality ($p = .307$) and no Condition by Scalp Laterality interaction ($p = .686$).

The primary purpose of the study was to investigate whether habitual use of cognitive reappraisal (as assessed by the ERQ-R) was associated with reduced amplitude of the LPP for the threatening pictures. Between 500 and 1,000 ms poststimulus onset a Pearson's correlation analysis (one-tailed) revealed no relationship between LPP amplitude in the threat condition and the reappraisal score in either the right ($r = .020$, $p = .471$) or the left ($r = .311$, $p = .120$) parietal clusters. Between 1,000 and 1,500 ms poststimulus onset a Pearson's correlation analysis revealed a significant inverse relationship between LPP amplitude in the threat condition and the reappraisal score in the right centro-parietal cluster ($r = -.614$, $p = .005$; see Figures 2A and 2B), but not in the left cluster ($r = .199$, $p = .231$). In other words, over right centro-parietal electrodes, between 1,000 and 1,500 ms after stimulus onset, the amplitude of the LPP was more attenuated for those participants who used cognitive reappraisal more frequently in everyday life.

To exclude the potential influence of emotional reactivity, as assessed by the trait STAI which indexes individual differences in proneness to anxiety, the influence by a different emotion regulation technique (expressive suppression), and gender, for the right centro-parietal electrode cluster we ran a partial correlation between LPP amplitude in the threat condition (1,000–1,500 ms) and the reappraisal score, with STAI trait, expressive suppression, and gender as control variables. The correlation between LPP

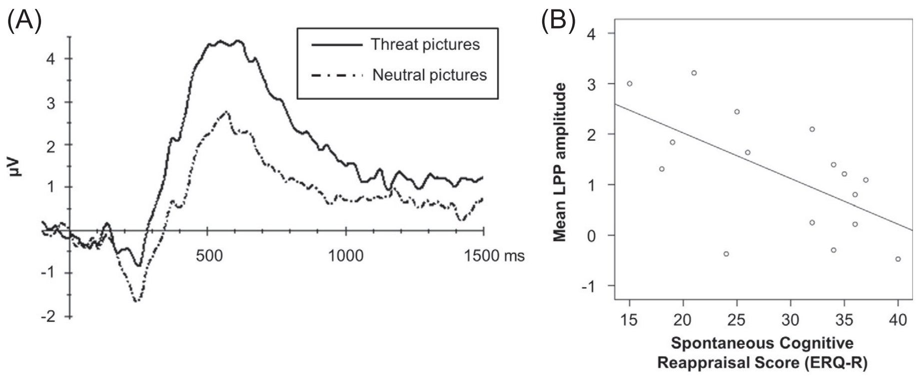

Figure 2. Plot of LPP and scatterplot of relationship between LPP amplitude and reappraisal score. (A) Grand-averaged ERPs for the threat (solid line) and neutral (dashed line) conditions, over right centro-parietal locations. (B) Scatterplot of the reappraisal scale of the ERQ (ERQ-R) and the amplitude of the threat-related LPP between 1,000 and 1,500 ms over right centro-parietal scalp.

amplitude in the threat condition and the reappraisal score remained significant, even after excluding the potential influence of emotional reactivity (i.e., trait anxiety), expressive suppression, and gender ($r = -.731$, $p = .003$, $df = 11$).

To test whether the relationship between habitual use of reappraisal and the LPP amplitude between 1,000 and 1,500 ms over right central-parietal scalp was specific to the threat condition, we carried out a Pearson's correlation between the ERQ-R and the LPP in the neutral condition, and this showed no significant association ($r = -.255$, $p = .171$). Further, we carried out a Pearson's correlation between the ERQ-R and the difference between the LPP amplitude in the threat versus the neutral condition (i.e., threat minus neutral LPP amplitude), which revealed a significant inverse relationship ($r = -.523$, $p = .019$). The relationship between the ERQ-R and the threat minus neutral LPP remained significant when controlling for the potential influence of emotional reactivity, expressive suppression, and gender ($r = -.555$, $p = .025$, $df = 11$).

Finally, we investigated whether the use of expressive suppression was related to the LPP amplitude between 500–1,000 ms and 1,000–1,500 ms, and no significant associations were observed (500–1,000 ms: left cluster, $r = .163$, $p = .55$; right cluster, $r = .14$, $p = .60$; 1,000–1,500 ms: left cluster, $r = .01$, $p = .99$; right cluster, $r = .04$, $p = .88$).

Discussion

The current experiment aimed to investigate the association between individual differences in the habitual use of cognitive reappraisal and the emotion-related late positive potential (LPP) component of the event-related potential. Our results showed that participants who used cognitive reappraisal more often in their daily life (as assessed by the ERQ-R) displayed decreased amplitude of the LPP over right centro-parietal scalp between 1,000 and 1,500 ms after image onset. The attenuation in LPP amplitude was specific to threat-related stimuli and was not present in response to emotionally neutral pictures. Our results could not be explained by individual differences in emotion reactivity (as assessed by trait anxiety), or by the use of another common method of regulating emotions, namely expressive suppression.

As expected, we found enhanced amplitudes of the EPN in response to threatening versus neutral images over occipito-parietal regions, in accordance with previous studies (Van Strien et al., 2009, 2014), providing strong evidence that the threatening images evoked the intended emotional response. Likewise, we observed greater LPP amplitude in response to threatening versus neutral images over centro-parietal regions between 500–1,000 ms and 1,000–1,500 ms after picture onset, in general agreement with previous studies (Hajcak et al., 2010; Lang & Bradley, 2010).

Our most important finding was that individual differences in the spontaneous use of cognitive reappraisal (as assessed via the ERQ-R) were associated with the amplitude of the LPP in response to threatening images. Specifically, the more frequent the self-reported use of reappraisal, the more the LPP amplitude was attenuated in response to threatening compared to neutral images, between 1,000 and 1,500 ms after stimulus onset, over right centro-parietal scalp. The observed decrease in LPP amplitude is in agreement with the vast majority of previous research that have shown that the LPP is reduced during (instructed) cognitive reappraisal (for reviews, see Hajcak et al., 2010, 2012), but here we show, for the first time, that the LPP is reduced via cognitive reappraisal under more natural conditions, that is, in the absence of experimental instruction. Attenuation of the LPP amplitude during down-regulation of emotion by reappraisal is generally explained as reflecting diminished arousal as a result of changes in stimulus meaning (Hajcak et al., 2010, 2012). This explanation is consistent with the current findings, where the tendency to use cognitive reappraisal in daily life, and hence to reinterpret the pictures in a way that reduces their affective impact, was associated with diminished amplitude of the LPP. The current findings are also in agreement with fMRI results showing that increased habitual use of cognitive reappraisal is associated with reduced activations in emotion-generative cortical regions such as the amygdala (Drabant et al., 2009).

The association between the LPP amplitude and self-reported use of cognitive reappraisal was found only in the 1,000–1,500 ms time-window, and there was no evidence for an association between 500 and 1,000 ms. Several studies have shown LPP modulations by (instructed) reappraisal at comparatively late stages of stimulus processing, for example, after 1,000 ms (Gan, Yang, Chen, & Yang, 2015) or 1,500 ms (Thiruchselvam et al., 2011) poststimulus onset. Modulation of the LPP at this relatively late stage of processing is in accordance with the process model of emotion regulation, in that reappraisal is a relatively time-consuming process that requires several stages of processing (i.e., attending to and then evaluating the meaning of the stimulus) before successful reinterpretation can be achieved. Indeed, the later portion of the LPP is thought to reflect appraisal of the meaning of the stimulus (Hajcak et al., 2010, 2012; MacNamara et al., 2009). Similarly, Gan et al. (2015) reported that the LPP amplitude was lowered by reappraisal only after 1,000 ms, and found that during the early period (400–1,000 ms) the LPP was *increased* for cognitive reappraisal, compared to passive viewing. A potential explanation for their finding is that the LPP during the early period is influenced by cognitive processes governing the implementation of the reappraisal strategy. The time-course of LPP modulation in the current study is also in accordance with findings by Moser, Hartwig, Moran, Jendrusina, and Kross (2014) who found that, in the context of instructions to positively reappraise picture content, trait reappraisal modulated the LPP after, but not before, 1,000 ms following picture presentation. Conversely, other studies have reported relatively early effects of reappraisal on the LPP, even beginning at 200 ms (Hajcak & Nieuwenhuis, 2006) to 400 ms (Moser, Krompinger, Dietz, & Simons, 2009) after picture onset. It could be that in the current study where the use of reappraisal was spontaneous rather than instructed, the effects on the LPP were not seen until after 1,000 ms post-picture onset, as implementation of the strategy was more cognitively demanding compared to an instructed reappraisal context.

The association between the LPP amplitude and spontaneous use of cognitive reappraisal was found over right, but not left, centro-parietal cortex. The right-lateralized pattern in the LPP is in line with recent findings by Zhang and Zhou (2014), who reported that participants in an automatic emotion control group had reduced right posterior LPP amplitude differences between high and low arousal emotional pictures, compared to a group with automatic emotion express tendencies. Together, this may suggest that the LPP over right centro-parietal scalp is particularly sensitive to individual differences in the use of emotion regulation techniques in the absence of experimental instruction. Moreover, fMRI data has revealed asymmetries in cortical responses as a function of habitual use of cognitive reappraisal, but these asymmetries have been found mainly in the prefrontal cortex (Kim, Cornwell, & Kim, 2012). In any case, it will be important for future studies to better understand the role and function of brain hemispheric asymmetries in the processing of emotional pictures in relation to individual differences in habitual emotion regulation.

We found no association between habitual use of expressive suppression and LPP amplitude in the current study, and we suggest two possible explanations. Firstly, the effectiveness of suppression to reduce negative affect has been shown to be reduced compared to reappraisal (Gross & Levenson, 1993), and, unlike reappraisal, it appears not to reduce activation in emotion-related cortical regions such as the amygdala and insula (Goldin et al., 2008). Secondly, suppression (a response-focused strategy) is thought to target different stages in the emotion generation process compared to reappraisal (an antecedent-focused strategy), and suppression likely affects later stages of emotion generation compared to reappraisal. Indeed, Goldin et al. (2008) found that reappraisal activated cortical areas related to emotion control in an early time-window (0–4.5 s) while suppression activated those regions in a later window (10.5–15 s). Moreover, a recent ERP study (Gan et al., 2015) found that while instructed reappraisal reduced the amplitude of the LPP, suppression did not lower the LPP amplitude, compared to passive viewing. Together, these considerations suggest that the lack of association between habitual use of expressive suppression and the amplitude of the LPP in the current study may be due to the reduced efficacy of suppression as a technique to regulate emotions, and that suppression may influence ERP components other than the LPP (e.g., the N2; Gan et al., 2015).

Several limitations of the current study should be acknowledged. Firstly, it is not clear to what extent the participants were using the strategy of cognitive reappraisal while viewing the pictures. Future research could probe the participants' regulation technique retrospectively after the experiment to more fully elucidate the nature of the participants' trial-by-trial regulation strategies. In this regard, it would also be useful to ask participants to retrospectively report whether they were using a more deliberate cognitive reappraisal strategy or alternatively a more automatic/implicit strategy, as it is known that spontaneous emotion regulation can encompass both types of strategies (Gyurak et al., 2011), depending on, for instance, the length of time that an individual has used a given technique. It is important to note, though, that the current results could not be explained by individual differences in expressive suppression as a strategy to down-regulate emotional reactions.

Secondly, we observed no association between self-reported habitual use of cognitive reappraisal and the behavioral outcome of the experiment (i.e., the threat ratings of the pictures). A number of studies have found that instructed forms of cognitive reappraisal led to reduced perceived intensity of negative or unpleasant stimuli (e.g., Hajcak & Nieuwenhuis, 2006; Paul et al., 2013) compared to passive viewing conditions, measured using explicit ratings of the intensity of the participant's emotional response (Hajcak & Nieuwenhuis, 2006), or the arousal and unpleasantness dimensions of the stimuli (Paul et al., 2013). In the current study the emotional intensity evoked by the pictures was not directly measured; instead, participants were asked to judge the threat value, which may not reflect the judgment of emotional intensity of the picture,[2] and could explain why we failed to observe an association between habitual cognitive reappraisal and threat ratings. Future studies should more directly measure the participants' emotional intensity, to investigate links between habitual reappraisal and self-reported intensity of affect evoked by the images.

While we did not explicitly control for emotional reactivity, we instead measured trait anxiety (using the STAI trait version), which is known to be a proxy for emotional reactivity (Kashdan, 2002), with high positive correlations ($r = \sim.70$) between the STAI trait version and different measures of emotional reactivity (e.g., Fox, Cahill, & Zougkou, 2010; Marshall, Wortman, Vickers, Kusulas, & Hervig, 1994). While the STAI measures general anxiety levels, more specific anxiety measures could be used in future studies, such as those measuring social anxiety, as different types of anxiety are known to influence different ERP components (e.g., Rossignol, Philippot, Bissot, Rigoulot, & Campanella, 2012). A further potential limitation in the study was the relatively small sample size, however our major finding (correlation between ERQ-R and LPP amplitude) was sufficiently strong as to produce statistical significance at the conventional levels and a large effect size. A retrospective power analysis of our main statistical result was carried out using the pwr (Champely, 2012) package in Q3 R-statistics (R Core Team, 2015). With $N = 16$, α set at 0.05, and $r = .615$ for one-tailed tests, analysis revealed a power ($1 - \beta$) value of 0.846, indicating a very high – over 85% – chance of detecting genuine effects. In summary, a Type II error was unlikely (Field, 2013).

Conclusions

The current study aimed to investigate the effect of spontaneous cognitive reappraisal on the LPP, which is sensitive to emotion-related processing. The habitual use of cognitive reappraisal is known to be associated with lower levels of negative affect, greater interpersonal functioning, and greater psychological and physical well-being (Gross & John, 2003). We found that a greater tendency to use spontaneous emotion regulation in everyday life was associated with reduced LPP amplitude to threatening pictures between 1,000 and 1,500 ms after stimulus onset, over right centro-parietal electrodes. Most previous research has shown LPP amplitude reductions during instructed cognitive reappraisal, but here we show, for the first time, that the LPP is attenuated via cognitive reappraisal under more ecologically valid conditions. Given the strong association between trait reappraisal and psychological health (Gross & John, 2003), the current findings suggest that the LPP may be a clinically relevant index of adaptive cognitive change as implemented in everyday life, that is, in the absence of explicit experimental instructions.

Conflicts of Interest

The authors declare that they have no competing interests.

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[2] Following Mogg et al. (2000), part of the threat rating was a judgment of the degree of physical harm or danger to others which the picture depicted, which could be unrelated to judgments about the perceived emotional intensity of the image.

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