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Time course of emotion-related responding during distraction and reappraisal

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Theoretical accounts of emotion regulation (ER) discriminate various cognitive strategies to voluntarily modify emotional states. Amongst these, attentional deployment (i.e. distraction) and cognitive change (i.e. reappraisal), have been shown to successfully down-regulate emotions. Neuroimaging studies found that both strategies differentially engage neural structures associated with selective attention, working memory and cognitive control. The aim of this study was to further delineate similarities and differences between the ER strategies reappraisal and distraction by investigating their temporal brain dynamics using event-related potentials (ERPs) and their patterns of facial expressive behavior. Twenty-one participants completed an ER experiment in which they had to either passively view positive, neutral and negative pictures, reinterpret them to down-regulate affective responses (reappraisal), or solve a concurrently presented mathematical equation (distraction). Results demonstrate the efficacy of both strategies in the subjective control of emotion, accompanied by reductions of facial expressive activity (Corrugator supercilii and Zygomaticus major). ERP results indicated that distraction, compared with reappraisal, yielded a stronger and earlier attenuation of the late positive potential (LPP) magnitude for negative pictures. For positive pictures, only distraction but not reappraisal had significant effect on LPP attenuation. The results support the process model of ER, separating subtypes of cognitive strategies based on their specific time course.

Keywords: emotion regulation; distraction; reappraisal; late positive potential; electromyography

INTRODUCTION

Emotional processing is a dynamic phenomenon composed of several successive stages (Gross, 2007; Wessa and Linke, 2009) that each may be targeted by multiple kinds of interventions to control emotional experiences. These active attempts to modify emotional states are referred to as emotion regulation (ER) strategies and include all '*extrinsic and intrinsic processes responsible for monitoring, evaluating, and modifying emotional reactions, especially their intensive and temporal features*' (Thompson, 1994, pp. 27–28). According to the 'process model' of ER (for reviews, see Gross and Thompson, 2007; Sheppes and Gross, 2011), five different families of ER strategies can be distinguished by their distinct features and time points at which they predominantly intervene in the emotional processing stream: situation selection, situation modification, attentional deployment, cognitive change and response modulation. Attentional deployment and cognitive change are considered to be antecedent-focused forms of ER (Gross and Thompson, 2007) as they each modulate emotional responses early in the emotion-generative trajectory, but on successive cognitive processing stages. So far, our empirical knowledge on how quickly the emotion-modulating effects of attentional deployment and cognitive change emerge and whether they differentially affect the various domains of emotional responding (i.e. experiential, expressive and physiological) is scarce. The aim of this study was, therefore, to directly contrast and dynamically assess the effects of both ER forms in order to highlight their commonalities and differences.

Attentional deployment describes any influence on emotional responding by redirecting attention within a certain situation (Gross and Thompson, 2007) with distraction referring to the shift of attention away from emotion-triggering aspects of a given situation, involving visual and internal cognitive processes (Ochsner and Gross, 2005). Recent functional neuroimaging (fMRI) studies reported attenuated self-reported negative affect after distraction through perceptual (Blair *et al.*, 2007), working memory (McRae *et al.*, 2010) or mathematical tasks (Kanske *et al.*, 2011) as well as concomitant decreased neural activation of affective appraisal structures (e.g. amygdala) and increased activation of cognitive control areas (e.g. prefrontal cortex). Furthermore, distraction has been shown to reduce autonomic parameters of emotional responding, including skin conductance level (Sheppes *et al.*, 2009) and startle eyeblink magnitude (Wangelin *et al.*, 2011).

The most widely studied type of cognitive change as another antecedent-focused ER strategy is reappraisal, which aims at modifying emotional responses by reinterpreting the meaning of an event to change its emotional impact. Indeed, reappraisal seems successful in down-regulating subjective and physiological correlates of emotion processing, i.e. self-reported emotional intensity (Ray *et al.*, 2010), facial expressivity (Ray *et al.*, 2010; Kim and Hamann, 2012), skin conductance level (McRae *et al.*, 2012) and heart rate (Hofmann *et al.*, 2009). On a neural level, down-regulating negative emotion by reappraisal was associated with decreased activity in the amygdala, ventral striatum and insula as well as increased activity in higher order control networks, including lateral ventral and orbital prefrontal cortex (Ochsner *et al.*, 2004; Eippert *et al.*, 2007; Goldin *et al.*, 2008). Recently, two fMRI studies contrasted both strategies directly (McRae *et al.*, 2010; Kanske *et al.*, 2011) and found stronger decreases in bilateral amygdala activity for distraction compared with reappraisal. As pointed out previously, ER strategies might differ in their temporal engagement during the ER process. The investigation of the temporal resolution of different ER strategies by use of event-related potentials (ERPs) seems very important. The late positive potential (LPP) is

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Table 1 Demographic data of the sample ($N = 21$) and behavioral performance during distraction trials

	Demographic Data
Sex (*N* female/male)	14/7
Age in years (mean ± SD; range)	20.5 ± 1.7; 19–27
Handedness (mean ± SD; range)	77.3 ± 19.3; 29–100
	Task performance[a]
Neutral images	
Accuracy (%)	85.23 (11.33)
Reaction times (ms)	3159.57 (360.10)
Negative images	
Accuracy (%)	80.83 (10.91)
Reaction times (ms)	3275.84 (347.45)
Positive images	
Accuracy (%)	82.10 (11.51)
Reaction times (ms)	3286.83 (355.13)

[a]We performed a repeated measures ANOVA on task performance (accuracy and reaction time data) with a 3-level within-subjects factor 'emotion' (neutral, negative and positive) that revealed no significant effects for accuracy, $F(2,40) = 2.538$, $P = 0.092$, but a significant effect for reaction times, $F(2,40) = 8.177$, $P = 0.001$, indicating that participants were faster to solve the mathematical equation with a neutral background image compared with a positive ($P = 0.002$) and negative ($P = 0.010$) background image.

probably the most adequate ERP component to be used for that purpose as it varies with the emotional impact of presented stimuli (Hajcak *et al.*, 2009) and as it has already been used to study the temporal dynamics of affective modulation through cognitive reappraisal (Hajcak and Nieuwenhuis, 2006; Foti and Hajcak, 2008; Krompinger *et al.*, 2008) and distraction (Thiruchselvam *et al.*, 2011; Wangelin *et al.*, 2011; Van Dillen and Derks, 2012), showing that both ER strategies were successful in reducing LPP magnitudes to emotional stimuli. However, to date only one ERP study, using the LPP as key dependent variable, directly contrasted reappraisal and distraction during the presentation of negative stimuli (Thiruchselvam *et al.*, 2011). The authors reported robust LPP attenuation to both ER strategies, with the effects of distraction occurring earlier (at 300 ms) and being stronger than effects of reappraisal (at 1500 ms). This study sought to extend these important findings by (i) using facial expressivity in addition to self-reported emotional experience and LPP magnitudes as valence-related physiological index of emotional responding, (ii) comparing the regulation of positive versus negative emotion and (iii) by using a different distraction manipulation from the one used by Thiruchselvam *et al.* (2011). In our study, distraction was operationalized by presenting arithmetic equations so that the participant‘s attention was occupied by a specified cognitive task and insufficient resources remained for the processing of concurrent emotional information. This conceptualization is in line with recent ER models (Gross, 2007), which define distraction as shifting attention away from the emotional content of the stimuli, implying different cognitive processes, such as shifting visual gaze and loading working memory. We chose this task to (i) assure task-compliance by acquiring accuracy and reaction time data (Table 1) and (ii) reduce variability in the strategies used by study participants.

For this study, we hypothesized that both ER strategies would lead to diminished LPP magnitudes to negative and positive stimuli when compared to passively viewing the pictures. Based on theoretical accounts on ER and previous results (Thiruchselvam *et al.*, 2011), we further predicted that distraction would diminish the LPP earlier than reappraisal. Based on previous findings on facial expressive behavior (Larsen *et al.*, 2003), we expected to detect a typical increase in Corrugator supercillii and Zygomaticus major EMG activity for negative and positive emotion respectively, as well as a respective decrease of these facial expressive responses during the employment of both ER strategies.

METHODS

Participants

Twenty-one young, healthy adults took part in the study after giving written informed consent (see Table 1 for demographic data). All of them were native German speakers, right-handed as assessed by the Edinburgh handedness inventory (Oldfield, 1971) and reported normal or corrected-to-normal vision. Exclusion criteria encompassed neurologic or cardiovascular diseases, lifetime history of head surgery or injury, dyscalculia, current or past mental disorder as assessed by the Structured Clinical Interview for DSM-IV (German version of the SCID-I and -II; Wittchen *et al.*, 1997) and current use of psychotropic medication. The study protocol was approved by the Ethics Committee of the Medical Faculty Mannheim, Heidelberg University.

Stimulus material

Emotion-inducing stimuli were 90 color photographs drawn from the International Affective Picture System (IAPS; Lang *et al.*, 2005).

Thirty positive, high arousing pictures displaying happy families, exciting sport scenes and romantic/erotic couples, 30 negative, high-arousing pictures depicting scenes of human violence, mutilation, accidents, loss and illness, and 30 neutral, low-arousing pictures showing human faces or people doing ordinary activities were selected. For more details on the pictures used in this study, i.e. IAPS identification numbers, normative and sample valence and arousal ratings, stimulus selection criteria as well as physical stimulus properties of the pictures, please see Supplementary Material A.

For the purpose of distraction, participants had to solve 3-operand arithmetic equations, including one subtraction and one addition (e.g. $8 + 3 - 7 = 5$; see Kanske *et al.*, 2011) and to indicate via button press as quickly and accurately as possible whether the displayed solution was correct or incorrect. Half of all equations were incorrect and were constructed to differ by 1 from the correct answer. In a pilot study, 154 of such arithmetic problems were tested in an independent sample of 16 healthy participants. From these, 90 equations were selected such that they all took on average more than 2000 ms to be solved. The selected equations were randomly assigned to the background picture category (negative, neutral, positive) such that there were no differences in RTs [overall mean: 3241 ms; $F(2,87) = 0.21$; $P = 0.979$].

Experimental task

The ER paradigm is an adapted version from Kanske *et al.* (2011) for use with ERPs. Prior to each picture presentation, a single-word instruction (VIEW, CALCULATE or DECREASE) was presented, signaling the strategy to be used during the following trial. During free-viewing (VIEW), participants were asked to view the picture attentively and to respond naturally to the content without trying to change upcoming emotional responses. During distraction (CALCULATE), participants were asked to solve the concurrently presented mathematical equation and to indicate via button press whether the displayed solution was correct or incorrect whilst ignoring the background picture. During cognitive reappraisal (DECREASE), participants were asked to cognitively diminish their emotional reactions by distancing themselves from the picture, by becoming a detached, uninvolved observer, or by thinking that the depicted situation is not real. Each picture was presented in the VIEW, CALCULATE and DECREASE condition, except for the neutral pictures that were not presented for reappraisal to not confuse participants by asking them to lower an emotional response to a non-affective stimulus. All trials were presented in an intermixed design. Each participant received a different

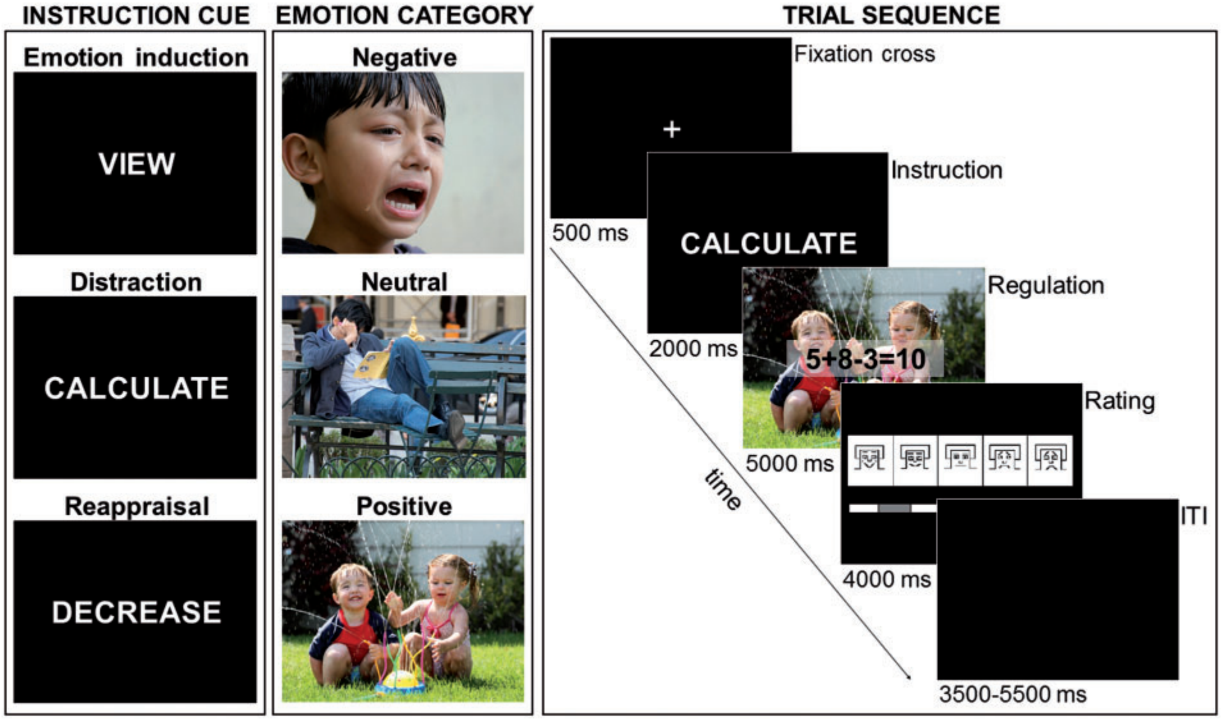

Fig. 1 Trial sequence. The example pictures resemble those in the experiment but are not part of the IAPS.

pseudo-randomized trial order with no more than three trials of the same valence category or regulation instruction appearing consecutively. To practice the ER strategies, eight example pictures were shown and the participant's responses were reviewed by the experimenters until they felt sure that the ER instructions were correctly understood.

Figure 1 illustrates the time course of one trial, beginning with a fixation cross (500 ms) to orient eye gaze on the center of the screen. A following instruction cue (2000 ms) signaled the participants to regulate their emotions according to the practiced strategies and was then replaced with the picture (5000 ms). For distraction trials, arithmetic problems were additionally presented as transparent overlay on the picture to allow for a solution of the problem. After picture offset, participants rated their current emotional experience on a 9-point scale using the Self-Assessment Manikin scale for valence (Bradley and Lang, 1994) ranging from unpleasant (1) via neutral (5) to pleasant (9). A variable inter-trial interval (3500–5500 ms) was presented prior to presentation of the next trial to permit recovery on all physiological measures. A total of five experimental blocks, separated by a brief rest, were administered. The complete experiment consisted of 240 trials and lasted about 65 min. Timing of all events was controlled using the standardized software Presentation (Neurobehavioral Systems, Inc., Albany, CA).

Physiological recording, instrumentation and data analysis

Raw electroencephalographic (EEG) data were recorded with sintered Ag/AgCl-electrodes from 60 scalp sites positioned according to the augmented International 10–20 system (American Electroencephalographic Society, 1991). Online, EEG signals were referenced to the right mastoid. Horizontal and vertical electrooculographic activity (EOG) was measured in a bipolar configuration laterally at the outer canthi of each eye and above and below the right eye. Electrode impedances were kept $<10\,k\Omega$. EEG and EOG data were registered continuously with a sampling rate of 1 kHz and 16-bit A/D conversion using BrainAMP amplifiers (Brain Products, Inc., Munich, Germany).

Offline analysis was performed with Brain Vision Analyzer II software (Brain Products GmbH, Munich, Germany). EEG data were down-sampled to 250 Hz, re-referenced to the mathematically linked mastoids and filtered with a 0.1 to 40-Hz (24 dB/oct) bandpass. An independent component analysis logarithm was applied to correct eye-blinks and other stereotypic artifacts (e.g. horizontal eye movement, heart beat). ERP epochs were extracted from −500 to 5000 ms relative to stimulus presentation and semiautomatically screened for contamination with unique artifacts (e.g. swallowing, electrode cable movements) with the following rejection criteria: peak-to-peak differences $>300\,\mu V$ within a trial, voltage steps of $50\,\mu V$ between sampling points and a maximum voltage difference $<0.50\,\mu V$ within 100 ms intervals. Segments were baseline corrected to the 250 ms pre-stimulus period. Stimulus-locked ERPs were constructed by separately averaging trials for each emotion category in the free-viewing condition and for positive and negative pictures that followed reappraisal and distraction instructions. Based on previous research indicating that positive slow waves are typically maximal at centroparietal sites (Keil *et al.*, 2002; Foti and Hajcak, 2008), the LPP was quantified as mean level of activity at an electrode cluster consisting of C1, Cz, C2, CP1, CPz, CP2, P1, Pz and P2 for the entire picture duration with the following separate time windows: 500–1000 ms (early LPP window) as well as 1000–2000 ms, 2000–3000 ms, 3000–4000 ms and 4000–5000 ms.

EMG activity was recorded as an index of facial emotion-expressive behavior. Miniature surface 4 mm-Ag/AgCl electrodes were placed in a bipolar fashion over the muscles Zygomaticus major and Corrugator supercilli on the left side of the face (cf. Fridlund and Cacioppo, 1986). EMG recordings were amplified using a BrainAmp ExG amplifier (Brain Products GmbH, Munich, Germany) and registered with a sampling frequency of 1 kHz. Raw EMG signals were filtered with a 30 Hz low cut-off, a 500 Hz high cut-off and 50 Hz notch filter, full-wave rectified and smoothed with a moving average over 125 ms. EMG scores were calculated as activity change relative to the baseline period (i.e. mean muscular activity during the last second prior to stimulus presentation) and averaged over five subsequent 1 s intervals, thus spanning the whole 5 s of stimulus presentation.

Statistical data analyses

Subjective emotional state ratings, EMG and ERP data were analyzed with SPSS Statistics version 20.0.0 (IBM, Chicago IL). To evaluate successful emotion induction during the free-viewing trials, we performed repeated-measures ANOVAs including a 3-level within-subject factor 'emotion' (negative, neutral and positive pictures) and a second, 5-level within-subject factor 'time' for LPP windows and EMG epochs. To evaluate regulation effects, separate repeated-measures ANOVAs were performed for negative and positive emotion for all dependent measures. For each picture valence, unregulated free-viewing trials were compared with distraction and reappraisal trials. The ANOVAs thus included the 3-level within-subject factor 'instruction' (view, distraction, reappraisal). Temporal dynamics of physiological parameters were assessed by including a 5-level factor 'time' (previously discussed). All ANOVA results were Greenhouse-Geisser corrected if assumption of sphericity was violated. Effects with a significance level of <0.05 were treated as statistically significant and effect sizes are reported using partial eta square (η_p^2). Post-hoc multiple comparisons were carried out using Bonferroni-adjusted corrections.

RESULTS

Manipulation check: emotion induction in self-report and physiology

Affective state ratings

We observed a significant main effect of emotion [$F(2,40) = 158.9$, $\varepsilon = 0.593$, $P < 0.001$, $\eta_p^2 = 0.888$]. Post-hoc pairwise comparisons indicated that negative pictures were experienced as more aversive and positive pictures experienced as more pleasant than neutral pictures (negative vs. neutral: $P < 0.001$; positive vs. neutral: $P < 0.001$; Figure 2A).

Emotion-expressive behavior

For Zygomaticus major activity, we observed a significant main effect of emotion [$F(2,38) = 11.848$, $\varepsilon = 0.384$, $P = 0.002$, $\eta_p^2 = 0.384$] such that positive stimuli elicited stronger EMG responses than neutral ($P = 0.008$) and negative stimuli ($P = 0.006$; Figure 2C). Further, a significant emotion x time interaction [$F(8,152) = 5.567$, $\varepsilon = 0.342$, $P = 0.003$, $\eta_p^2 = 0.227$] indicated that positive pictures elicited larger Zygomaticus responses compared with neutral pictures during seconds 3 to 5 and compared with negative pictures already during seconds 2 to 5.

For Corrugator supercilii, a significant main effect of emotion was present [$F(2,38) = 15.21$, $P < 0.001$, $\varepsilon = 0.673$, $\eta_p^2 = 0.445$] with increased corrugator activity during presentation of negative, compared with pleasant ($P = 0.001$) and neutral pictures ($P = 0.007$; Figure 2B). The significant emotion × time interaction, $F(8,152) = 3.347$, $P < 0.001$, $\varepsilon = 0.200$, $\eta_p^2 = 0.389$, indicated that negative images elicited stronger corrugator responses compared with neutral pictures for seconds 2–5 and relative to positive pictures for the whole picture presentation.

ERP responses

The 3 (emotion) × 5 (time) repeated-measures ANOVA revealed significant main effects of emotion [$F(2,40) = 6.346$, $P = 0.004$, $\eta_p^2 = 0.241$] and time [$F(4,80) = 6.574$, $\varepsilon = 0.358$, $P = 0.009$, $\eta_p^2 = 0.247$] as well as a significant emotion x time interaction [$F(8,160) = 11.964$, $\varepsilon = 0.576$, $P < 0.001$, $\eta_p^2 = 0.374$].

We calculated separate analyses for each LPP time window; the resulting statistical indices are displayed in Table 2. For the 500–1000 ms and the 1000–2000 ms time window, the LPP magnitude differed as a function of emotion category with post-hoc pairwise comparisons indicating a greater positivity for negative versus neutral pictures and positive versus neutral pictures, but no differences between positive and negative pictures. In later time windows (2000–5000 ms), no significant LPP magnitude differences between the three emotion conditions occurred. Figure 2D presents the stimulus-locked ERP waveforms associated with positive, neutral and negative stimuli during the free-viewing condition.

Regulation of negative affect: self-report and physiology

Affective state ratings

For negative pictures, a significant main effect of instruction [$F(2,40) = 51.84$, $P < 0.001$, $\eta_p^2 = 0.722$] was observed, indicating that both ER strategies were effective in reducing negative affect compared with free viewing (view vs. distraction: $P < 0.001$; view vs. reappraisal: $P < 0.001$). Distraction and reappraisal did not differ in their effects on emotional experience ratings ($P = 1.00$; Figure 3A).

Emotion-expressive behavior

Analyses of Corrugator supercilii activity (Figure 3B) revealed significant main effects of instruction [$F(2,38) = 8.39$, $P = 0.001$, $\eta_p^2 = 0.306$], time [$F(4,76) = 6.57$, $\varepsilon = 0.359$, $P < 0.001$, $\eta_p^2 = 257$] and a significant interaction of instruction × time [$F(8,152) = 7.625$, $\varepsilon = 0.376$, $P < 0.001$, $\eta_p^2 = 0.286$], reflecting that regulated trials showed reduced expressive corrugator activity in comparison with unregulated trials as early as 2 s after picture onset. A direct comparison of the temporal dynamics of both ER strategies indicated that distraction relative to reappraisal was less successful in reducing negative affect-related corrugator expressivity within the fourth and fifth second of picture presentation ($P < 0.05$).

ERP responses

ERP waveforms elicited by negative pictures in the view, distraction and reappraisal conditions are depicted in Figure 3C. The 3 (instruction) × 5 (time window) repeated measures ANOVA on LPP magnitudes revealed main effects of instruction [$F(2,40) = 9.569$, $P < 0.001$, $\eta_p^2 = 0.324$] and time [$F(4,80) = 36.335$, $\varepsilon = 0.418$, $P < 0.001$, $\eta_p^2 = 0.645$] as well as a significant instruction x time interaction [$F(8,160) = 5.816$, $\varepsilon = 0.459$, $P = 0.001$, $\eta_p^2 = 0.225$].

We calculated separate ANOVAs for the 5 LPP windows; the resulting statistical indices are displayed in Table 2. In the early window (500–1000 ms), LPP magnitudes did not vary as a function of instruction, whereas the LPP magnitude was modulated by instruction in the time window from 1000 to 2000 ms with significant LPP reductions for distraction relative to free viewing and a trend toward significance for reappraisal as compared with free viewing. In the following two LPP time windows (2000–3000 ms, 3000–4000 ms), ERPs were diminished under both regulation conditions compared with free viewing, whereas in the last time window (4000–5000 ms) significantly attenuated LPP magnitudes were only observed for distraction but not for reappraisal.

Regulation of positive affect: self-report and physiology

Affective state ratings

For positive pictures, a significant main effect of instruction was observed [$F(2,40) = 68.24$, $P < 0.001$, $\eta_p^2 = 0.773$). Planned pairwise

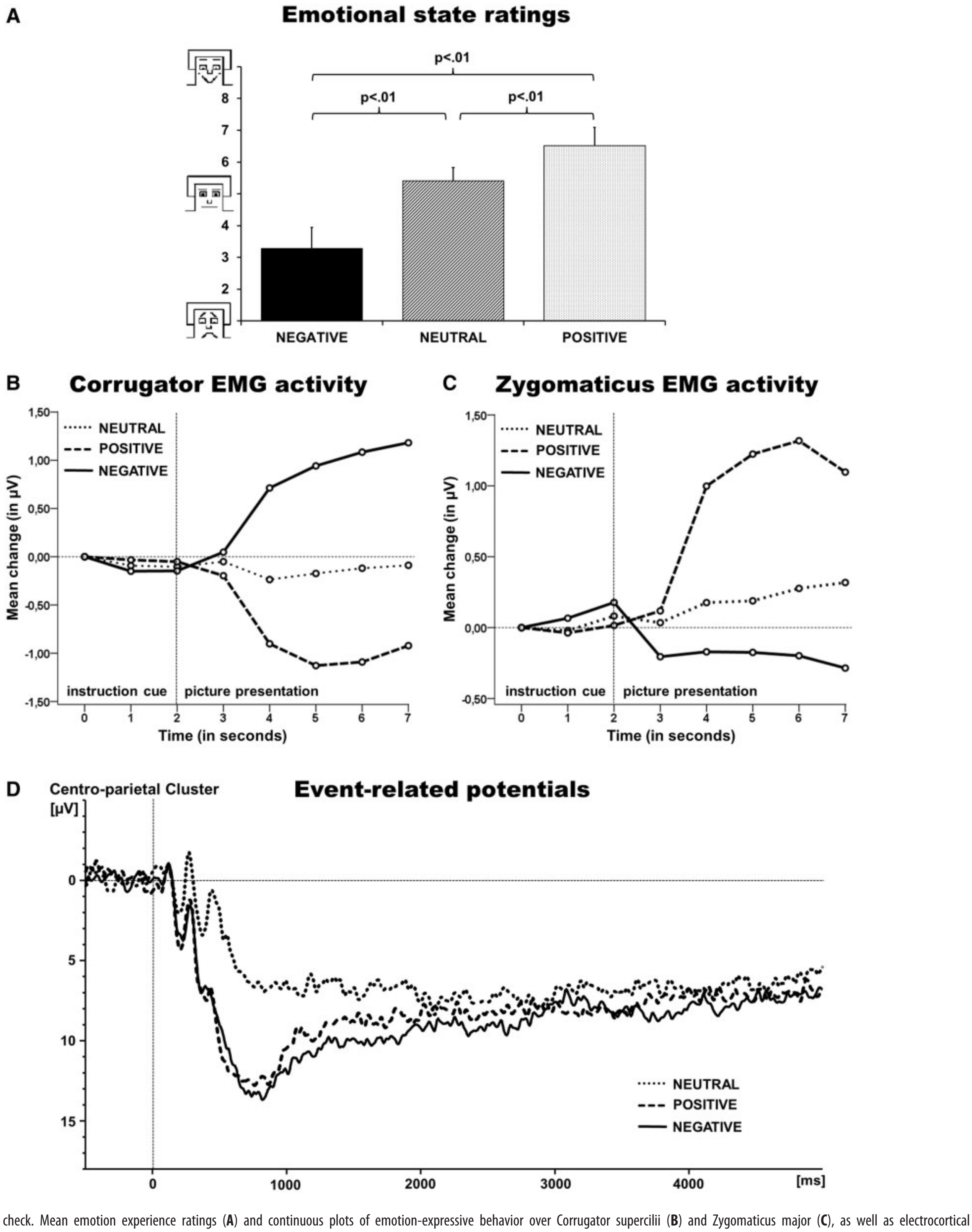

Fig. 2 Manipulation check. Mean emotion experience ratings (**A**) and continuous plots of emotion-expressive behavior over Corrugator supercilii (**B**) and Zygomaticus major (**C**), as well as electrocortical responses (**D**) during free viewing trials. For graphical purposes, the ERP waveforms were low-pass filtered at 20 Hz.

comparisons indicated that both forms of ER were successful in diminishing positive affect relative to free viewing (view vs. distraction: $P < 0.001$; view vs. reappraisal: $P < 0.001$) and that reappraisal led to a greater reduction of positive affect than distraction ($P = 0.001$; Figure 4A).

Emotion-expressive behavior

Analyses of Zygomaticus major EMG activity (Figure 4B) revealed a significant main effect of instruction [$F(2,38) = 11.909$, $\varepsilon = 0.602$, $P < 0.001$, $\eta_p^2 = 0.385$] and a significant instruction × time interaction [$F(8,152) = 5.587$, $\varepsilon = 0.232$, $P = 0.009$, $\eta_p^2 = 0.227$], indicating that the

Table 2 Statistics of the ANOVAs and post hoc pair-wise comparisons for each of the five LPP time windows for the emotion induction effect as well as the regulation effects (comparison between view, distraction and reappraisal) for positive and negative affect

LPP window	Emotion induction effect	
	Statistics	Bonferroni-corrected pairwise comparisons
500–1000 ms	$F(2,40) = 30.175$, $P < 0.001$, partial $\eta^2 = 0.601$	Negative vs. neutral: $P < 0.001$; positive vs. neutral: $P < 0.001$; negative vs. positive: $P = 1.00$
1000–2000 ms	$F(2,40) = 7.656$, $P = 0.002$, partial $\eta^2 = 0.277$	Negative vs. neutral: $P = 0.007$; positive vs. neutral: $P = 0.055$; negative vs. positive: $P = 0.491$
2000–3000 ms	$F(2,40) = 1.021$, $P = 0.370$	—
3000–4000 ms	$F(2,40) < 1.00$, $P = 0.382$	—
4000–5000 ms	$F(2,40) < 1.00$, $P = 0.485$	—

LPP window	Regulation of negative affect		Regulation of positive affect	
	Statistics	Bonferroni-corrected pairwise comparisons	Statistics	Bonferroni-corrected pairwise comparisons
500–1000 ms	$F(2,40) < 1.0$, $P = 0.432$	—	$F(2,40) < 1.0$, $P = 0.989$	—
1000–2000 ms	$F(2,40) = 5.741$, $P = 0.006$, partial $\eta^2 = 0.223$	View vs. distraction: $P = 0.008$ View vs. reappraisal: $P = 0.079$ Distraction vs. reappraisal: $P = 0.702$	$F(2,40) = 4.725$, $\varepsilon = 0.724$, $P = 0.026$, partial $\eta^2 = 0.191$	View vs. distraction: $P = 0.063$ View vs. reappraisal: $P = 1.00$ Distraction vs. reappraisal: $P = 0.146$
2000–3000 ms	$F(4,40) = 13.345$, $P < 0.001$, partial $\eta^2 = 0.400$	View vs. distraction: $P < 0.001$ View vs. reappraisal: $P = 0.008$ Distraction vs. reappraisal: $P = 0.145$	$F(2,40) = 7.918$, $\varepsilon = 0.783$, $P = 0.003$, partial $\eta^2 = 0.284$	View vs. distraction: $P = 0.015$ View vs. reappraisal: $P = 0.729$ Distraction vs. reappraisal: $P = 0.025$
3000–4000 ms	$F(2,40) = 8.620$, $P = 0.001$, partial $\eta^2 = 0.301$	View vs. distraction: $P = 0.001$ View vs. reappraisal: $P = 0.041$ Distraction vs. reappraisal: $P = 0.433$	$F(2,40) = 6.009$, $\varepsilon = 0.776$, $P = 0.010$, partial $\eta^2 = 0.231$	View vs. distraction: $P = 0.035$ View vs. reappraisal: $P = 0.410$ Distraction vs. reappraisal: $P = 0.084$
4000–5000 ms	$F(2,40) = 10.825$, $P < 0.001$, partial $\eta^2 = 0.351$	View vs. distraction: $P < 0.001$ View vs. reappraisal: $P = 0.094$ Distraction vs. reappraisal: $P = 0.122$	$F(2,40) = 2.277$, $P = 0.116$	—

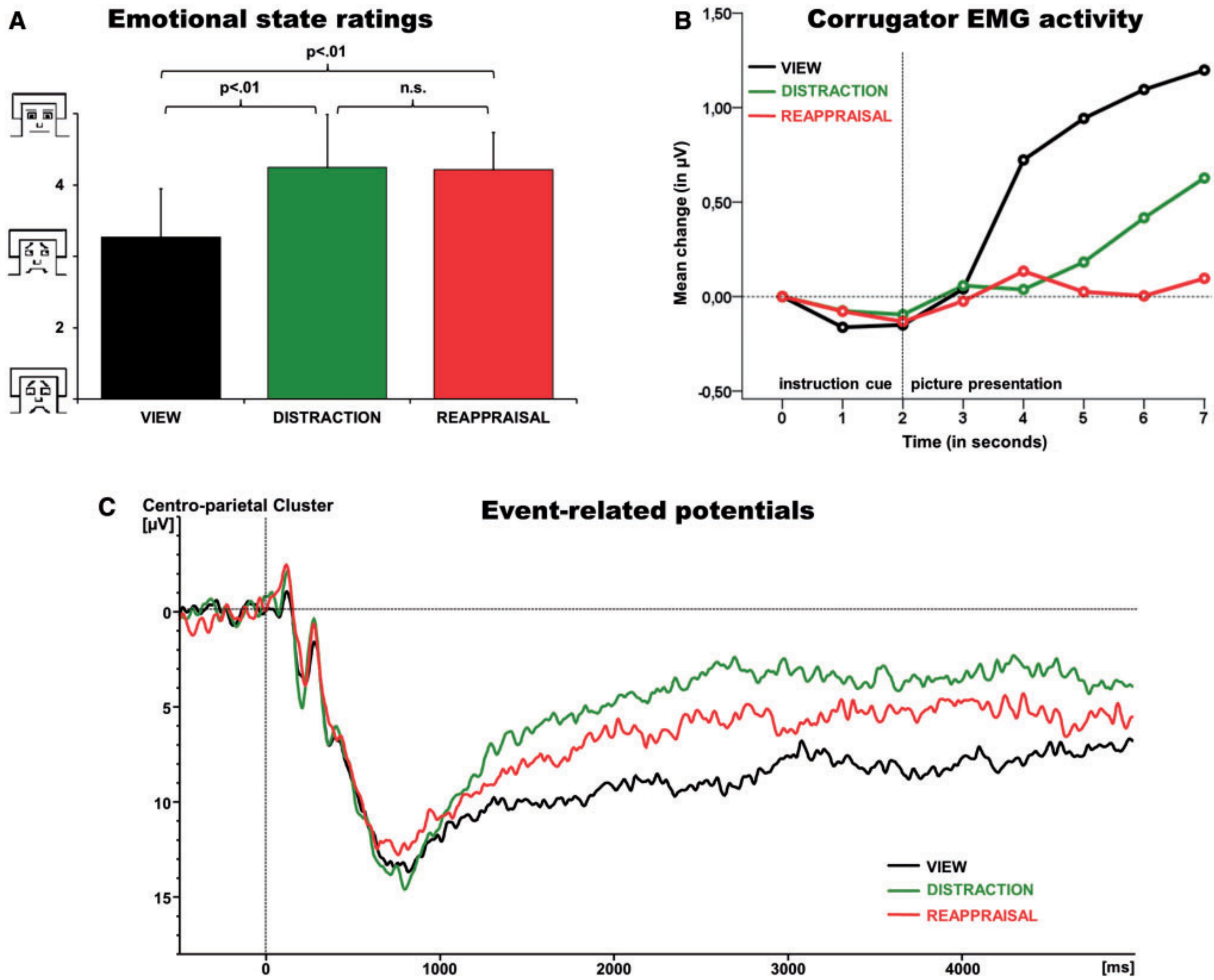

Fig. 3 Regulation of negative emotion. Emotion experience effects (**A**), emotion-expressive behavior effects over Corrugator supercilii (**B**) and electrocortical responses (**C**) for the free-viewing trials compared with the two regulated conditions during negative picture presentation. For graphical purposes, the ERP waveforms were low-pass filtered at 20 Hz.

differentiation between ER and free viewing trials occurred as early as 2 s after stimulus onset and continued for the whole stimulus duration. Direct contrasts did not show any significant differences between the two ER strategies (all $P > .10$).

ERP responses

Stimulus-locked ERP waveforms triggered by positive pictures for the three ER instructions are shown in Figure 4C. The 3 (instruction) × 5 (time) repeated-measures ANOVA revealed main effects of instruction [$F(2,40) = 4.182$, $\varepsilon = 0.785$, $P = 0.033$, $\eta_p^2 = 0.173$], time [$F(4,80) = 30.519$, $\varepsilon = 0.338$, $P < 0.001$, $\eta_p^2 = 0.604$] and a significant instruction × time interaction [$F(8,160) = 6.066$, $\varepsilon = 0.366$, $P = 0.001$, $\eta_p^2 = 0.233$].

Separate ANOVAs were calculated for the respective time windows; the resulting statistical indices are depicted in Table 2. We observed no effect of instruction in the earliest LPP window (500–1000 ms), whereas in the 1000–2000 ms time window a significant effect of instruction was observed with a trend towards attenuated magnitudes during distraction compared with free viewing. Under distraction, attenuation of LPP magnitudes was strongest and significant for the 2000–3000 ms and 3000–4000 ms time windows, but not for the 4000–5000 ms window. In none of the LPP time, windows reappraisal had a significant effect.

DISCUSSION

The goal of this study was to further elucidate similarities and differences of two ER strategies, i.e. attentional deployment (distraction) and cognitive reappraisal, with respect to their impact on emotional responding and their temporal dynamics. Indeed, both ER strategies were effective in controlling emotion as indicated by altered subjective, facial expressive and electrophysiological responses.

In detail, we found a successful decrease of subjective positive and negative emotion experience as well as marked reductions of facial expressivity over Corrugator supercilii and Zygomaticus major during both distraction and reappraisal. These findings support earlier research demonstrating a modulation of emotion-expressive behavior in response to antecedent-focused (reappraisal: Lee *et al.*, 2009; Ray *et al.*, 2010) and response-focused ER strategies (suppression: Dan-Glauser and Gross, 2011). Additionally, ERPs were decreased during both forms of ER during negative picture viewing with the effects of distraction occurring earlier (1000–2000 ms) than reappraisal

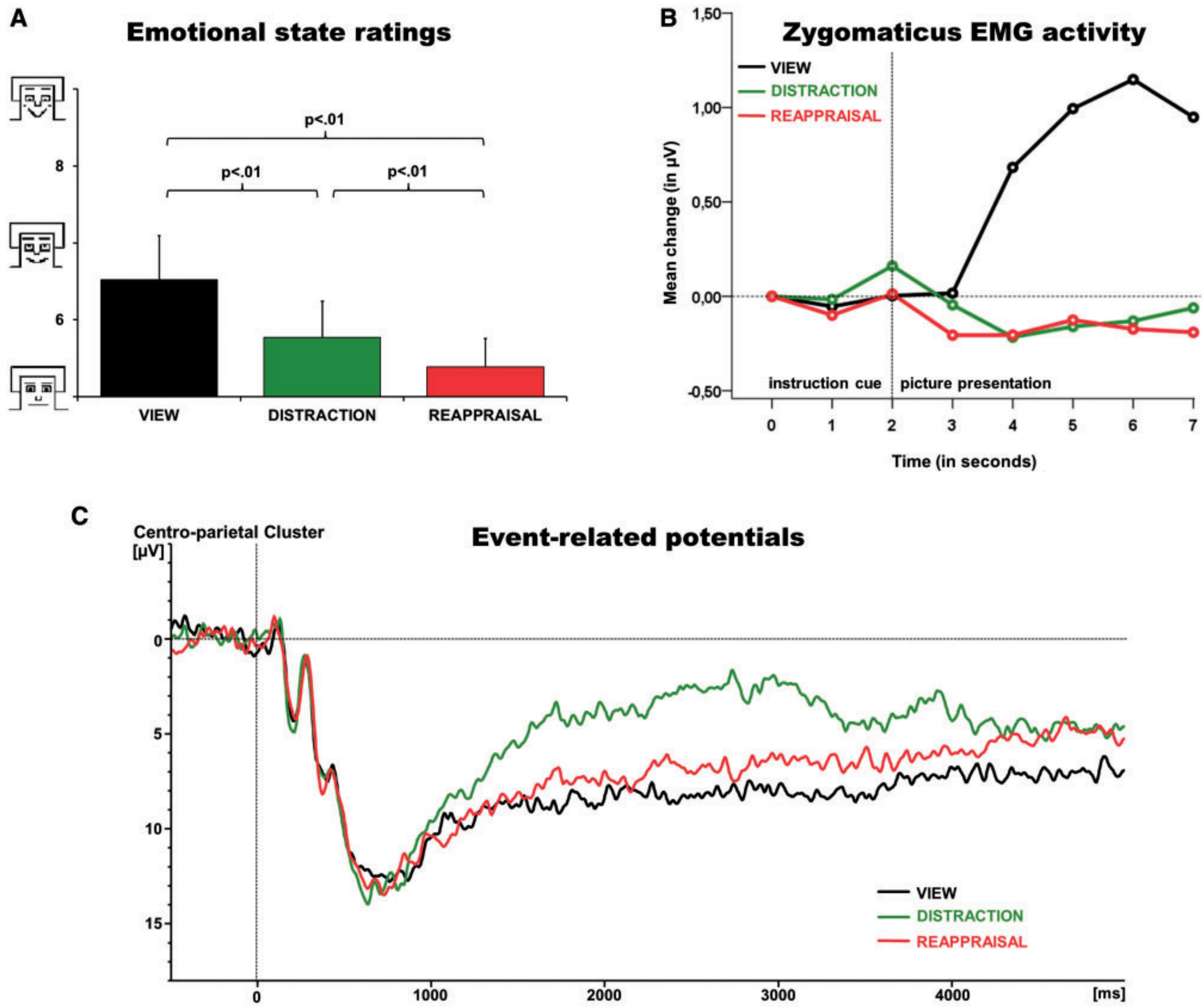

Fig. 4 Regulation of positive emotion. Emotion experience effects (**A**), emotion-expressive behavior effects over Zygomaticus major (**B**) and electrocortical responses (**C**) for the free-viewing trials compared with the two regulated conditions during positive picture presentation. For graphical purposes, the ERP waveforms were low-pass filtered at 20 Hz.

(2000–3000 ms) and yielding to a stronger attenuation of the emotion-sensitive LPP magnitudes. For positive pictures, however, only distraction but not reappraisal led to a significant attenuation of LPP magnitudes.

Particularly for negative affect, our findings are in accordance with the suggestion that using top–down ER techniques, such as reappraisal (Hajcak and Nieuwenhuis, 2006; Foti and Hajcak, 2008; Krompinger *et al.*, 2008) and distraction (MacNamara *et al.*, 2011; Thiruchselvam *et al.*, 2011; Wangelin *et al.*, 2011) leads to reductions in self-reported affect and concomitant reductions of LPP magnitudes. Importantly, in this study, the effects of ER on LPP magnitudes were only found during time intervals of 1000 to 4000 ms after stimulus presentation, whereas affective differentiation during free viewing was less pronounced in these time windows. A reason for the absent LPP modulation during free viewing might be our strict stimulus selection procedure. Recent studies showed significantly enhanced LPP magnitudes for neutral social cues versus neutral non-living objects (Ferri *et al.*, 2012), possibly indicating a higher degree of attentional resource allocation to human faces. In our study, all pictures, i.e. positive, negative and neutral ones, depicted human beings, potentially leading to less pronounced LPP differentiation between affective categories. Regulatory effects on LPP magnitudes occurred after the affective differentiation which indicates that a decrease in LPP magnitudes not only reflects a change in emotional state but also top–down cognitive processes involved in the here applied ER strategies. It appears that, once such cognitive processes are initiated, they last longer than the observed attenuation of emotions due to continued decreased attentional resource allocation and/or a lower degree of perceptual processing of emotional stimuli on LPP reductions. Supporting the relevance of such attentional processes on LPP modulation, Ferrari *et al.* (2008) found that not only emotional significance but also task relevance (i.e. focusing attention to or away from affectively engaging pictures) modulated the LPP in that the lowest LPP magnitude was found for neutral non-target compared with neutral target pictures and the largest LPP response for emotional target pictures.

Contrasting both ER instructions directly, important differences became apparent mainly during positive picture viewing. For self-reported affect, down-regulation of positive emotions was more successful during reappraisal than distraction. This finding expands prior work showing that distraction may be less effective than reappraisal for diminishing affective states (pain: Kalisch *et al.*, 2006; fear:

Kamphuis and Telch, 2000; depression: Kross and Ayduk, 2008). For neural responses (ERPs), however, we observed the opposite pattern: whereas distraction resulted in significant LPP attenuation, cognitive reappraisal did not modulate LPP magnitudes to positive stimuli. So far, only one other study (Krompinger *et al.*, 2008) demonstrated attenuated LPPs during the cognitive regulation of positive emotion via reappraisal by showing predominantly erotic pictorial stimuli. Yet, in our study, we used a greater variety of positively valenced semantic picture contents (i.e. exciting sport scenes, cute children, happy families) and failed to demonstrate LPP modulation through reappraisal. Interestingly, recent studies (Weinberg and Hajcak, 2010) have shown smaller LPP magnitudes for these type of positive images as opposed to erotic stimuli, a finding that might explain the lack of reliable emotion induction and regulation effects for positive images in this study. Another reason for the lack of LPP modulation might result from habitual tendencies to regulate emotions during everyday life. As individuals most often purposefully regulate negative affective states in daily life situations, this might be easier and more rapidly applied in experimental tasks that require control of negative emotion. Positive affect (such as amusement or happiness) is naturally experienced without attempts to voluntarily down-regulate emotion, thereby probably lacking rapidity and efficacy in laboratory settings. On the other hand, reappraisal to decrease positive emotion reduced EMG activity over the Zygomaticus major comparably with distraction. The dissociation of results might suggest that reappraisal influences indices of facial expressivity and physiological arousal differentially. Previous reports on negative emotion indeed provide evidence for this notion showing that reappraisal to decrease emotion during disgust-inducing film clips (Gross, 1998) or negative IAPS pictures (Kim and Hamann, 2012) significantly diminished self-reported affect and facial expressivity but did not alter indices of physiological arousal (i.e. skin conductance responses).

For negative emotion, we found earlier and stronger LPP attenuation for distraction than for reappraisal. This result provides evidence for the timing hypothesis motivated by the process model of ER (Gross, 2007), where it is assumed that distraction operates earlier in the ER process because individuals are not attending to or encoding the emotional aspects of the scene. Early in the emotion-generative trajectory, incoming stimulus information compete for limited attentional resources that operate as filter to determine which information gains access to more elaborate processing (Hubner *et al.*, 2010). Distraction as an early-stage ER strategy is assumed to prevent any irrelevant affective information from being processed as the limited attentional resources are mainly allocated to the goal-relevant information. Reappraisal operates at a later stage and necessitates the direction of attention to the emotional stimulus in order to reframe its meaning, thus the LPP magnitudes might not be diminished as quickly and strongly as during distraction. Such differential effects of distraction and reappraisal on the LPP magnitude converge with recently published neuroimaging findings (McRae *et al.*, 2010; Kanske *et al.*, 2011) showing that distraction in contrast to reappraisal leads to a stronger down-regulation of amygdala activation in response to positive and negative pictures.

Our ERP findings also indicate that distraction modulated the LPP after emotional information was already differentiated from neutral information as revealed by significant early LPP effects during free viewing. These results suggest that attentional resources were allocated to the emotional scenes before regulatory effects of distraction started operating. This corresponds to the motivational theory of emotion (Lang and Bradley, 2010) which states that emotional stimuli immediately prompt a cascade of reflexive responses mediated by limbic motivational circuits. From an evolutionary perspective, it seems essential that a fast, involuntary attentional orienting and related sympathetic response mobilization towards danger cues persists despite concurrent distraction in order to secure demands of survival (Öhman *et al.*, 2000). Nevertheless, this result contradicts previous ERP findings (Hajcak and Nieuwenhuis, 2006) indicating an onset of LPP modulation by ER around 200 ms after stimulus presentation. These divergences may result from several dissimilarities in the experimental designs. First, previous studies have employed a blocked rather than intermixed design. In a single reappraisal-block (Moser *et al.*, 2006) participants might have changed expectations about the upcoming pictures. Conscious adjustment of expectations about stimuli may represent an effective antecedent-focused strategy for the cognitive control of emotion. In this regard, previous studies may have tested controlled generation of emotional responses, which might occur earlier, as opposed to controlled regulation. Second, this study combined the assessment of several ER strategies within one experiment. One recent study that also directly contrasted distraction and reappraisal within an ERP study (Thiruchselvam *et al.*, 2011) also found significant differences between LPPs during reappraisal and free viewing of negative pictures only after 1500–1700 ms post stimulus onset. Finally, our additional integration of positive pictures in one study design might have further contributed to a later LPP modulation.

The current results have to be interpreted in light of some limitations. First, although the LPP component is mostly sensitive to arousal, we only assessed subjective valence ratings of emotional state. We did so in order to properly differentiate the effects of ER on both positively and negatively valenced stimuli. Previous research has repeatedly shown strong quadratic correlations between valence and arousal (Greenwald *et al.*, 1989) and results of recent ERP studies revealed similar patterns of valence and arousal ratings after successful down-regulation of emotion (Bernat *et al.*, 2011; Thiruchselvam *et al.*, 2011). Second, the use of explicit, self-report emotional state ratings of emotional experience bears the risk of introducing response biases, e.g. demand effects or social desirability. In our study, participants completed the Social Desirability Scale (SDS; German version: Stöber, 1999) which is commonly used as a measure of an individual's tendency to provide responses demanded in an experiment. SDS scores were uncorrelated with subjective reappraisal success (negative affect: $r = 0.099$, $P = 0.668$; positive affect: $r = -0.045$, $P = 0.846$). Nevertheless, it cannot be completely ruled out that demand effects influenced online emotional state ratings. A final, but major limitation of the present and previous studies is the focus on short-term effects. On this note, distraction has been proven to be the more efficient in immediately reducing an emotionally stressful response and thus has been implemented in different psychotherapeutic strategies (e.g. dialectic behavioral therapy). However, it is possible that reappraisal is a more beneficial strategy for adaptive emotional processing in the long run and thus a valuable avenue for cognitive-behavioral interventions aiming at preventing relapse in recurrent mental disorders characterized by emotional dysregulation (e.g. bipolar affective disorder). Initial evidence comes from recent ERP studies showing that reappraising negative scenes enhances subsequent cognitive control (Moser *et al.*, 2010) and results in diminished emotion-sensitive LPP magnitudes upon re-exposure (Thiruchselvam *et al.*, 2011). Future studies would therefore benefit greatly from investigating the short- versus long-term consequences of various ER strategies depending on personality and psychopathology.

SUPPLEMENTARY DATA

Supplementary data are available at *SCAN* online.

REFERENCES

American Electroencephalographic Society. (1991). American Electroencephalographic Society guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, *8*(2), 200–2.

Bernat, E.M., Cadwallader, M., Seo, D., Vizueta, N., Patrick, C.J. (2011). Effects of instructed emotion regulation on valence, arousal, and attentional measures of affective processing. *Developmental Neuropsychology*, *36*(4), 493–518.

Blair, K.S., Smith, B.W., Mitchell, D.G., et al. (2007). Modulation of emotion by cognition and cognition by emotion. *Neuroimage*, *35*(1), 430–40.

Bradley, M.M., Lang, P.J. (1994). Measuring emotion: the self-assessment Manikin and the semantic differential. *Journal of Behaviour Therapy and Experimental Psychiatry*, *25*(1), 49–59.

Dan-Glauser, E.S., Gross, J.J. (2011). The temporal dynamics of two response-focused forms of emotion regulation: experiential, expressive, and autonomic consequences. *Psychophysiology*, *48*(9), 1309–22.

Eippert, F., Veit, R., Weiskopf, N., Erb, M., Birbaumer, N., Anders, S. (2007). Regulation of emotional responses elicited by threat-related stimuli. *Human Brain Mapping*, *28*(5), 409–23.

Ferrari, V., Codispoti, M., Cardinale, R., Bradley, M.M. (2008). Directed and motivated attention during processing of natural scenes. *Journal of Cognitive Neuroscience*, *20*(10), 1753–61.

Ferri, J., Weinberg, A., Hajcak, G. (2012). I see people: the presence of human faces impacts the processing of complex emotional stimuli. *Social Neuroscience*, *7*(4), 436–43.

Foti, D., Hajcak, G. (2008). Deconstructing reappraisal: descriptions preceding arousing pictures modulate the subsequent neural response. *Journal of Cognitive Neuroscience*, *20*(6), 977–88.

Fridlund, A.J., Cacioppo, J.T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, *23*(5), 567–89.

Goldin, P.R., McRae, K., Ramel, W., Gross, J.J. (2008). The neural bases of emotion regulation: reappraisal and suppression of negative emotion. *Biological Psychiatry*, *63*(6), 577–86.

Greenwald, M.K., Cook, E.W., Lang, P.J. (1989). Affective judgment and psychophysiological response: dimensional covariation in the evaluation of pictorial stimuli. *Journal of Psychophysiology*, *3*, 51–64.

Gross, J.J. (1998). Antecedent- and response-focused emotion regulation: divergent consequences for experience, expression, and physiology. *Journal of Personality and Social Psychology*, *74*(1), 224–37.

Gross, J.J. (2007). *Handbook of Emotion Regulation*. New York: Guilford Press.

Gross, J.J., Thompson, R.A. (2007). Emotion regulation: conceptual foundations. In: Gross, J.J. editor. *Handbook of Emotion Regulation*. New York: Guilford Press, pp. 3–24.

Hajcak, G., Dunning, J.P., Foti, D. (2009). Motivated and controlled attention to emotion: time-course of the late positive potential. *Clinical Neurophysiology*, *120*(3), 505–10.

Hajcak, G., Nieuwenhuis, S. (2006). Reappraisal modulates the electrocortical response to unpleasant pictures. *Cognitive Affective and Behavioral Neuroscience*, *6*(4), 291–7.

Hofmann, S.G., Heering, S., Sawyer, A.T., Asnaani, A. (2009). How to handle anxiety: the effects of reappraisal, acceptance, and suppression strategies on anxious arousal. *Behaviour Research and Therapy*, *47*(5), 389–94.

Hubner, R., Steinhauser, M., Lehle, C. (2010). A dual-stage two-phase model of selective attention. *Psychological Review*, *117*(3), 759–84.

Kalisch, R., Wiech, K., Critchley, H.D., Dolan, R.J. (2006). Levels of appraisal: a medial prefrontal role in high-level appraisal of emotional material. *Neuroimage*, *30*(4), 1458–66.

Kamphuis, J.H., Telch, M.J. (2000). Effects of distraction and guided threat reappraisal on fear reduction during exposure-based treatments for specific fears. *Behaviour Research and Therapy*, *38*(12), 1163–81.

Kanske, P., Heissler, J., Schonfelder, S., Bongers, A., Wessa, M. (2011). How to regulate emotion? Neural networks for reappraisal and distraction. *Cerebral Cortex*, *21*(6), 1379–88.

Keil, A., Bradley, M.M., Hauk, O., Rockstroh, B., Elbert, T., Lang, P.J. (2002). Large-scale neural correlates of affective picture processing. *Psychophysiology*, *39*(5), 641–9.

Kim, S.H., Hamann, S. (2012). The effect of cognitive reappraisal on physiological reactivity and emotional memory. *International Journal of Psychophysiology*, *83*(3), 348–56.

Krompinger, J.W., Moser, J.S., Simons, R.F. (2008). Modulations of the electrophysiological response to pleasant stimuli by cognitive reappraisal. *Emotion*, *8*(1), 132–7.

Kross, E., Ayduk, O. (2008). Facilitating adaptive emotional analysis: distinguishing distanced-analysis of depressive experiences from immersed-analysis and distraction. *Personality and Social Psychology Bulletin*, *34*(7), 924–38.

Lang, P.J., Bradley, M.M. (2010). Emotion and the motivational brain. *Biological Psychology*, *84*(3), 437–50.

Lang, P.J., Bradley, M.M., Cuthbert, B.N. (2005). *International Affective Picture System (IAPS): Affective Ratings of Pictures and Instruction Manual*. Technical report A-6 Gainesville, FL: Center of Research in Psychophysiology, University of Florida.

Larsen, J.T., Norris, C.J., Cacioppo, J.T. (2003). Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology*, *40*(5), 776–85.

Lee, H., Shackman, A.J., Jackson, D.C., Davidson, R.J. (2009). Test-retest reliability of voluntary emotion regulation. *Psychophysiology*, *46*(4), 874–9.

MacNamara, A., Ferri, J., Hajcak, G. (2011). Working memory load reduces the late positive potential and this effect is attenuated with increasing anxiety. *Cognitive Affective and Behavioral Neuroscience*, *11*(3), 321–31.

McRae, K., Ciesielski, B., Gross, J.J. (2012). Unpacking cognitive reappraisal: goals, tactics, and outcomes. *Emotion*, *12*(2), 250–5.

McRae, K., Hughes, B., Chopra, S., Gabrieli, J.D., Gross, J.J., Ochsner, K.N. (2010). The neural bases of distraction and reappraisal. *Journal of Cognitive Neuroscience*, *22*(2), 248–62.

Moser, J.S., Hajcak, G., Bukay, E., Simons, R.F. (2006). Intentional modulation of emotional responding to unpleasant pictures: an ERP study. *Psychophysiology*, *43*(3), 292–6.

Moser, J.S., Most, S.B., Simons, R.F. (2010). Increasing negative emotions by reappraisal enhances subsequent cognitive control: a combined behavioral and electrophysiological study. *Cognitive Affective and Behavioral Neuroscience*, *10*(2), 195–207.

Ochsner, K.N., Gross, J.J. (2005). The cognitive control of emotion. *Trends in Cognitive Science*, *9*(5), 242–9.

Ochsner, K.N., Ray, R.D., Cooper, J.C., et al. (2004). For better or for worse: neural systems supporting the cognitive down- and up-regulation of negative emotion. *Neuroimage*, *23*(2), 483–99.

Öhman, A., Flykt, A., Lundqvist, D. (2000). Unconscious emotion: evolutionary perspectives, psychophysiological data and neuropsychological mechanisms. In: Lane, R.D., Nadel, L., editors. *Cognitive Neuroscience of Emotion*. New York: Oxford University Press, pp. 296–327.

Oldfield, R.C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113.

Ray, R.D., McRae, K., Ochsner, K.N., Gross, J.J. (2010). Cognitive reappraisal of negative affect: converging evidence from EMG and self-report. *Emotion*, *10*(4), 587–92.

Sheppes, G., Catran, E., Meiran, N. (2009). Reappraisal (but not distraction) is going to make you sweat: physiological evidence for self-control effort. *International Journal of Psychophysiology*, *71*(2), 91–6.

Sheppes, G., Gross, J.J. (2011). Is timing everything? Temporal considerations in emotion regulation. *Personality and Social Psychology Review*, *15*(4), 319–31.

Stöber, J. (1999). Die Soziale-Erwünschtheits-Skala-17 (SES-17): Entwicklung und erste Befunde zu Reliabilität und Validität [The Social Desirability Scale-17 (SDS-17): Development and first findings on reliability and validity]. *Diagnostica*, *45*(4), 173–7.

Thiruchselvam, R., Blechert, J., Sheppes, G., Rydstrom, A., Gross, J.J. (2011). The temporal dynamics of emotion regulation: an EEG study of distraction and reappraisal. *Biological Psychology*, *87*(1), 84–92.

Thompson, R.A. (1994). Emotional regulation: a theme in search for definition. In: Fox, N.A., editor. *The Development of Emotion Regulation: Behavioral and Biological Considerations*. Vol. 59(2–3). Monographs of the Society for Research in Child Development, Ann Arbor, MI, USA.

Van Dillen, L.F., Derks, B. (2012). Working memory load reduces facilitated processing of threatening faces: an ERP study. *Emotion*, *12*(6), 1340–9.

Wangelin, B.C., Low, A., McTeague, L.M., Bradley, M.M., Lang, P.J. (2011). Aversive picture processing: effects of a concurrent task on sustained defensive system engagement. *Psychophysiology*, *48*(1), 112–6.

Weinberg, A., Hajcak, G. (2010). Beyond good and evil: the time-course of neural activity elicited by specific picture content. *Emotion*, *10*(6), 767–82.

Wessa, M., Linke, J. (2009). Emotional processing in bipolar disorder: behavioural and neuroimaging findings. *International Reviews in Psychiatry*, *21*(4), 357–67.

Wittchen, H.-U., Zaudig, M., Fydrich, T. (1997). *SKID-I. Strukturiertes Klinisches Interview für DSM-IV [Structural clinical interview for DSM-IV axis I disorders]*. Göttingen (Germany): Hogrefe.