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Previously reappraised: the lasting effect of description type on picture-elicited electrocortical activity

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To examine whether reappraisal modifies responses to subsequent encounters with stimuli, participants viewed neutral and unpleasant pictures that were preceded by negative or neutral descriptions which served as reappraisal frames. A half an hour later, the same pictures were presented, without preceding frames; EEG was recorded and participants rated each picture on arousal and valence. In line with previous work, unpleasant compared to neutral pictures elicited more positive early- (359 ms), mid- (1074 ms) and late-latency (2436 ms) centrally-distributed ERP components. Pictures previously preceded by negative compared to neutral reappraisal frames were rated as more unpleasant and more emotionally arousing; these pictures elicited a larger mid-latency (1074 ms) occipital positivity. Together, the data suggest that reappraisal exerts an enduring effect on both subjective and neural responses to stimuli.

Keywords: ERPs; reappraisal; IAPS; late positive potential; emotion regulation; PCA

Emotion regulation strategies help us to respond adaptively to the emotional ups and downs of everyday life. One of the most flexible and efficacious regulation strategies is reappraisal, which involves reinterpreting the meaning of emotionally evocative stimuli. By changing the initial appraisal of a stimulus' affective value, reappraisal can effectively modulate subjective reports of emotion, facial expression and autonomic arousal (Gross and Levenson, 1997; Gross, 1998; Jackson *et al.*, 2000; Dillon and LaBar, 2005; Hajcak and Nieuwenhuis, 2006). Neuroimaging studies of reappraisal implicate increased activity in regions linked to cognitive control, including the prefrontal and cingulate cortex, which modulate activity in regions implicated in affective appraisal, such as the amygdala (e.g. Eippert *et al.*, 2007; McRae *et al.*, 2010; for a review, see Phan *et al.*, 2005; Ochsner and Gross, 2008).

Event-related potentials (ERPs) also have been used to provide more temporally fine-grained indices of the effects of reappraisal. The late positive potential (LPP) is a positive-going ERP that begins parietally ~200 ms following stimulus onset, and is larger throughout the stimulus presentation duration for emotional compared to neutral pictures and words (Cuthbert *et al.*, 2000; Schupp *et al.*, 2000; Dillon *et al.*, 2006; Hajcak *et al.*, 2007; Foti and Hajcak, 2008; Hajcak and Olvet, 2008; Pastor *et al.*, 2008). Using the LPP as an index of emotional arousal, Hajcak and Nieuwenhuis (2006) found that when participants were asked to reappraise unpleasant pictures, the LPP was reduced relative to the control condition. Moreover, reductions in self-reported emotional intensity were predicted by reductions in the LPP. Similar modulations in the LPP following more open-ended emotion regulation instructions also have been reported (Moser *et al.*, 2006; Krompinger *et al.*, 2008).

Most studies of cognitive reappraisal have asked participants to self-generate reappraisals on a stimulus-by-stimulus basis, which models the need to generate reappraisals relevant to unique real-life experiences. This has the disadvantage, however, of introducing inter- and intra-participant variability in the specific reappraisals used and raises the additional possibility that some of reappraisal's effects could be attributable to the need to generate—rather than implement—an affect-altering stimulus interpretation. To get around these issues, Foti and Hajcak (2008) and MacNamara *et al.* (2009) had participants view pictures that were preceded by neutral (e.g. 'These people are boarding an early morning flight') or negative (e.g. 'This plane was the target of a terrorist bomb') descriptions that served as 'reappraisal frames' that guided each participant's appraisal of the meaning of each image. Consistent with previous work on self-generated reappraisals, neutrally framed pictures elicited smaller LPPs and altered self-reported ratings of picture emotionality. Together, these studies suggest that changes in how a stimulus is appraised—whether driven by an internally generated reappraisal or guided by an externally provided reappraisal frame—are sufficient to alter neural activity and self-report measures of emotion.

This begs a new question, however. If reappraisals are effective at modulating emotion in the moment, how enduring

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are these effects? Given that emotionally evocative stimuli and situations can and often do recur, this question has real-world and clinical relevance. For example, cognitive behavioral therapies (CBTs) are used to treat mood, anxiety and substance abuse disorders, and a key component of CBT involves reappraisal-like training in rethinking the logic behind maladaptive appraisals (Beck, 1979). No studies to date, however, have directly examined the durability of specific reappraisals over time. Despite evidence of the effectiveness of CBT (e.g. Sanderson and McGinn, 2001; Butler *et al*., 2006; Curry and Becker, 2008; Hofmann and Smits, 2008; Stewart and Chambless, 2009), then, it remains unclear whether changes in meaning associated with reappraisal affect neural and self-report indices of emotional responses to subsequent encounters with emotionally evocative stimuli.

Though they do not involve reappraisals *per se*, memory studies that pair neutral pictures or words with emotional stimuli during encoding suggest that reappraisal could have lasting effects. For example, in a recognition task, neutral pictures previously presented against unpleasant or pleasant compared to neutral backgrounds elicited greater activation in brain areas associated with emotional processing (Smith *et al*., 2004b)—and evoked larger late parietal positivities (Smith *et al*., 2004a). Similar results have been found using neutral words presented in emotional compared to neutral sentences (Maratos *et al*., 2001; Maratos and Rugg, 2001). This work indirectly suggests that reappraisal frames might influence subsequent encounters with emotional stimuli.

To address this issue more directly, the present study had participants view neutral and unpleasant pictures that initially were preceded by negative or neutral reappraisal frames. Approximately 30 min later, participants passively viewed the same pictures, *without preceding frames*, while electroencephalography (EEG) was recorded and participants made self-report ratings following each image. Based on the notion that manipulations of meaning would create a relatively lasting change in the mental representation of the stimulus, it was expected that the LPP and self-report ratings would be modulated by the type of frame—even though the frame had been paired with the image 30 min earlier. In particular, we predicted that negative frames and unpleasant pictures would elicit larger positive-amplitude ERP components, as well as more unpleasant and more arousing self-report ratings. We also believed that the effect of picture type might have a different spatial and temporal distribution than the effect of reappraisal frame, because reappraisals would have to be recalled from memory and might therefore have a later impact on the LPP. To this end, temporospatial principal components analysis (PCA) was used in order to parse the potential independent and overlapping contributions of the effects of picture type and reappraisal frame on ERP components, and to facilitate comparison with prior work on reappraisal frames (i.e. MacNamara *et al*., 2009).

METHODS

Participants

Twenty-nine undergraduate students (12 male, 17 female) participated in the study. One participant was excluded due to poor quality EEG data, and therefore 28 participants (12 male, 16 female) were included in the final EEG analyses; all 29 participants were included in the analyses of self-report picture ratings. The study was approved by the Stony Brook University Institutional Review Board (IRB) and all participants received course credit.

Stimulus materials

Pictures and descriptions were taken from Foti and Hajcak (2008) and MacNamara and colleagues (2009)—a complete list of neutral pictures and descriptions can be found in MacNamara and colleagues (2009); unpleasant pictures and descriptions are listed in Foti and Hajcak (2008). The 50 unpleasant pictures (e.g. war scenes, sad faces) and 50 neutral images (e.g. household objects, neutral faces) were selected from the International Affective Picture System (IAPS; Lang *et al*., 2005). Normative ratings indicated that unpleasant pictures were less pleasant (valence $M = 2.88$, s.d. $= 0.94$) and more emotionally arousing ($M = 5.63$, s.d. $= 0.82$), than neutral pictures ($M = 4.78$, s.d. $= 0.50$ and $M = 3.51$, s.d. $= 0.95$), respectively (ratings were reverse-scored so that higher numbers indicate more pleasant and higher arousal ratings; MacNamara *et al*., 2009). For each picture, a negative and neutral audio description was created. Before seeing each picture, participants heard either the neutral (e.g. 'These people are boarding an early morning flight') or negative (e.g. 'This plane was the target of a terrorist bomb') description of the upcoming picture that served as a reappraisal frame.

In the first part of the experiment, one-half of neutral and one-half of unpleasant pictures were preceded by negative frames (the other half were preceded by neutral frames). Thirty minutes later, participants viewed the same pictures without frames while EEG was recorded and self-report ratings were obtained. Self-report ratings were not obtained at time 1 because we believed that this might have influenced EEG and self-report ratings at time 2. By considering their subjective response to each picture at time 1, frame and picture pairings might have been strengthened for participants; in addition, participants might have felt the need to be consistent between their ratings at time 1 and 2. A delay of 30 min between the first and second presentations of the pictures was chosen because this falls outside the time window for short-term memory (e.g. Peterson and Peterson, 1959), thus ensuring that any lasting effects of reappraisal could not be attributed to short-term effects of reappraisal on the storage and representation of pictures. Moreover, a delay of 30 min is in line with delays used in previous studies of long-term memory for emotional stimuli (e.g. Hamann *et al*., 1999). Indeed, the delay resembled the study-test interval in memory studies (Ochsner, 2000), during which time participants' attention is occupied by an unrelated task. In the present study, research assistants were trained to converse casually with participants (e.g. 'What classes are you taking?') while they completed the EEG setup, in order to decrease the likelihood that participants would spend time reflecting on the regulation task they had just completed.

Two versions of the task were created; participants were randomly assigned to one version or the other. Whether or not a participant heard the negative or neutral description for a specific picture depended on the task version: unpleasant pictures that were framed negatively (or neutrally) in one version of the task were framed neutrally (or negatively) in the other version of the task. Likewise, neutral pictures that were framed negatively (or neutrally) in one version of the task were framed neutrally (or negatively) in the other version. Thus, the correspondence between picture and description type was counter-balanced across participants.[1] The order of pictures (neutral or unpleasant) varied randomly for each participant in both the first and second portions of the experiment and all participants saw all pictures both times. Each picture was displayed in color at the full size of the monitor (48.26 cm). Participants were seated ~60 cm from the screen and the images occupied ~40° of visual angle horizontally and vertically.

Procedure

Participants were first told that they would see a variety of pictures; before each picture they would hear a description of the content of the upcoming picture. They were instructed to simply view the pictures and that no response was required. At the beginning of each trial, a white fixation cross was presented against a black background for 6000 ms as an audio description of the upcoming picture was delivered; all descriptions lasted between 2000 and 5000 ms. Each picture was then displayed for 3000 ms. The inter-trial interval was 1000 ms, during which time a white fixation cross was presented against a black background. Participants performed 10 practice trials to familiarize themselves with the procedure. Following the practice trials, all participants viewed 100 pictures, with breaks after every 25 pictures.

Next, EEG sensors were attached and participants were told that they would once again be viewing the same pictures, and that after viewing each picture, they would rate it on two visual analog scales (Lang, 1980)—one for pleasantness and one for emotional intensity. Participants were told they would use the valence scale to rate the extent to which they felt the picture evoked pleasant or unpleasant emotions. This scale depicted five characters that ranged from happy to unhappy; the numbers '1–9' were presented below the characters, with the number '1' corresponding to the most happy figure, and '9' corresponding to the least happy figure. Participants were told they would rate the 'strength' of their emotional response to pictures using the arousal scale, which ranged from excited to calm. Five characters were depicted displaying a strong visceral response to no visceral response; the numbers '1–9' were again presented below the characters. Participants were told that '1' represented a strong visceral response (e.g. stimulated, jittery, wide-awake) and '9' represented a non-visceral response (e.g. relaxed, calm, dull, sleepy). Participants were encouraged to use any point on the scale; on both scales, '5' represented the midpoint. Both sets of ratings have been reverse-scored so that a score of 9 represents pleasant valence and high arousal.

After ~30 min had passed, all pictures were presented for the second time; as before, each picture was presented for 3000 ms in random order, this time *without prior descriptions*. EEG was recorded and participants used the valence and arousal scales to rate each picture immediately after its presentation. The inter-trial interval was again 1000 ms, during which time participants viewed a white fixation cross on a black background. Breaks were again given every 25 trials.

EEG recording

Continuous EEG was recorded using an elastic cap and the ActiveTwo BioSemi system (BioSemi, Amsterdam, Netherlands). Sixty-four electrode sites were used, based on the 10/20 system, as well as one electrode on each of the left and right mastoids. Four facial electrodes recorded the electrooculogram (EOG) generated from eyeblinks and eye movements: vertical eye movements and blinks were measured with two electrodes placed ~1 cm above and below the right eye; horizontal eye movements were measured with two electrodes placed ~1 cm beyond the outer edge of each eye. The EEG signal was pre-amplified at the electrode to improve the signal-to-noise ratio and amplified with a gain of 16×. The data were digitized at 24 bit resolution with a sampling rate of 512 Hz using a low-pass fifth order sinc filter with a half-power cutoff of 102.4 Hz. Each active electrode was measured online with respect to a common mode sense (CMS) active electrode producing a monopolar (non-differential) channel. Off-line analyses were performed using Brain Vision Analyzer software (Brain Products, Gilching, Germany). Data were re-referenced to the average of electrical activity from all 64 scalp sites and band-pass filtered with low and high cutoffs of 0.1 and 30 Hz, respectively. The EEG was segmented for each trial beginning 500 ms prior to picture onset and continuing for 3500 ms (the entire picture duration). For each trial, the baseline was defined as the 500 ms prior to picture onset.

Eye blink and ocular corrections were made using the method developed by Gratton *et al.* (1983). Noisy data due to technical problems on isolated electrodes necessitated the replacement of data from PO4 in two subjects, Pz in two

[1] Negatively and neutrally described picture content was balanced across versions.

subjects, P2 in one subject, F6 in one subject and C1 in one subject. Data were interpolated from the closest four electrodes in each case.

Artifact analysis identified a voltage step of more than 50.0 μV between sample points, a voltage difference of 300.0 μV within a trial, and a maximum voltage difference of <0.50 μV within 100 ms intervals. Additional artifacts were identified through visual inspection. These intervals were rejected from individual channels in each trial.

PCA

ERP components of interest were quantified using temporospatial PCA. PCA extracts linear combinations of data that distinguish patterns of electrocortical activity across all time points and electrode sites. Conditions were created by collapsing across each set of 25 trials to yield four conditions (i.e. averages) per participant: neutrally described neutral pictures, negatively described neutral pictures, neutrally described unpleasant pictures and negatively described unpleasant pictures. A temporal PCA was first performed on the data (Dien and Frischkoff, 2004), using all 1792 time points (512 samples per second multiplied by a total trial-plus-baseline length of 3500 ms) per trial as variables and considering as observations all 28 subjects, 64 channels and four conditions. After the temporal PCA, a spatial PCA was performed using recording sites (electrodes) as variables and all participants, conditions and temporal factor scores as observations.

Temporospatial factors are described by spatial factor 'loadings' that represent linear contributions of recording sites for a given temporal factor (which itself is described by a linear combination of time points). Factor 'scores' quantify each factor across subject and condition. These summary measures can be translated back into voltages by multiplying the factor scores by the appropriate spatial and temporal loadings (for the desired channel and time point) and the corresponding spatial and temporal standard deviations (Dien *et al.*, 2003).

The PCA was conducted using the ERP PCA Toolbox (Dien, 2008) for MatLab (The MathWorks Inc., Natick, MA) using the covariance matrix and Kaiser normalization (as suggested by Dien *et al.*, 2005). The temporal PCA yielded nine factors based on the resulting Scree plot (Cattell, 1966; Cattell and Jaspers, 1967). These were submitted to Promax rotation, the preferred rotation for this step according to simulation results by Dien *et al.* (2007). Following this, a spatial PCA was performed on each temporal factor and Infomax was used to rotate to independence in the spatial domain (as per simulations by Dien *et al.*, 2007). Six spatial factors were extracted for each temporal factor, yielding a total of 54 temporospatial factor combinations. Of these, 14 factors accounted for >1% of the variance each and were retained for further examination. In order to directly assess timing and spatial voltage distributions, the factors were translated back into voltages using the method described above. According to Dien and colleagues (2005) and others (e.g. Fabiani *et al.*, 1987; Kayser and Tenke, 2003, 2005), the most effective means of deciding which factors to subject to statistical analyses while reducing the chance of Type I errors is to evaluate factors according to *a priori* knowledge about the ERP components relevant to the experimental design. Thus, based on visual inspection of the timecourse and spatial distribution of factors, seven factors that appeared to represent ERP components of interest to the paradigm were retained for statistical analyses; together, these factors accounted for 43% of the variance. Statistical analyses were performed using PASW (Version 17.0) General Linear Model software.

RESULTS

Self-report ratings

Table 1 presents means and standard deviations for self-report ratings of valence and arousal for each trial type. A 2 (description type: neutral, negative) × 2 (picture type: neutral, unpleasant) repeated-measures ANOVA revealed that valence ratings were lower (more unpleasant) overall for unpleasant pictures $F(1,28) = 141.85$, $P < 0.0001$, $\eta_p^2 = 0.84$ and for pictures that previously had been framed negatively $F(1,28) = 54.52$, $P < 0.0001$, $\eta_p^2 = 0.66$. Additionally, there was a significant interaction between frame and picture type $F(1,28) = 26.68$, $P < 0.0001$, $\eta_p^2 = 0.49$. A Bonferroni-corrected post hoc comparison (critical $P = 0.05/2 = 0.025$) indicated that the difference between negative and neutral frames was larger for neutral than unpleasant pictures $t(28) = 5.17$, $P < 0.0001$. That is, frame type had less of an effect on valence ratings for unpleasant compared to neutral pictures.

Arousal ratings were higher overall (more arousing) for unpleasant as compared to neutral images $F(1,28) = 239.76$, $P < 0.0001$, $\eta_p^2 = 0.90$ and for pictures that had followed negative as compared to neutral frames $F(1,28) = 53.07$, $P < 0.0001$, $\eta_p^2 = 0.66$. Additionally, there was a significant interaction between frame and picture type $F(1,28) = 32.99$, $P < 0.0001$, $\eta_p^2 = 0.54$. A Bonferroni-corrected post hoc comparison (critical $P = 0.05/2 = 0.025$) again indicated that description type had less of an effect on arousal ratings for unpleasant compared to neutral pictures $t(28) = 5.74$, $P < 0.0001$.

Table 1 Self-report mean ratings (and standard deviations) according to picture and description type

Picture type	Description type	Valence self-report	Arousal self-report
Neutral	Neutral	5.28 (0.79)	2.25 (0.85)
	Negative	3.52 (0.90)	4.08 (1.67)
Unpleasant	Neutral	3.47 (0.72)	4.50 (1.06)
	Negative	2.55 (0.54)	5.24 (1.22)

Note: Ratings were made on a scale of 1–9; higher ratings indicate more pleasant and more emotionally arousing pictures.

Comparison with previous work

In our previous work (MacNamara *et al.*, 2009), participants viewed the same pictures and heard the same reappraisal frames as in the current study, however they made self-report ratings of pictures immediately following their initial presentation. We compared ratings of arousal and valence made in the previous study with those made in the current study in order to determine whether they differed following a delay. In our previous work, negatively described pictures were rated an average of 4.7 (s.d. = 1.63) units on the arousal scale and neutrally described pictures were rated an average of 2.65 (s.d. = 1.09) units. In the current study, negatively described pictures were rated an average of 4.66 (s.d. = 1.38) on the arousal scale, compared to neutrally described pictures, which were rated an average of 3.38 (s.d. = 0.92) units. Thus, negatively compared to neutrally described pictures were rated an average of 0.77 units more arousing in our initial study (MacNamara *et al.*, 2009) when ratings were obtained immediately after the initial pairing of the frame and picture $t(57) = 2.59$, $P < 0.02$.

On the other hand, in our initial study, negatively framed pictures were rated an average of 2.88 (s.d. = 0.97) units on the valence scale, whereas neutrally described pictures were rated an average of 4.41 (s.d. = 0.77) units. In the current study, negatively framed pictures were rated an average of 3.04 (s.d. = 0.62) units on the valence scale, compared to neutrally described pictures, which were rated an average of 4.38 (s.d. = 0.67) units. Thus, valence ratings for negatively compared to neutrally framed pictures were comparable between studies (M difference = 0.19; $P > 0.47$).

Grand average ERPs

Figure 1 presents the grand-averaged waveforms at representative midline recording sites prior to the PCA. Unpleasant pictures appeared to elicit more positive ERP amplitudes from ~500 to 2800 ms following picture presentation at central (Cz) and parieto-occipital (POz) recording sites; a polarity reversal (i.e. the ERP was more negative) was evident at frontal sites (AFz) such that unpleasant pictures elicited more negative amplitudes. Pictures that were described negatively elicited more positive amplitudes than neutrally described pictures at central and parieto-occipital sites beginning around 750 ms after picture onset; like the effect of picture type, a polarity reversal of this effect was evident at frontal sites.

PCA

PCA factors are typically referred to in terms of their factor numbers; for instance, TF4/SF3 would refer to the third spatial factor on the fourth temporal factor. Instead of this conventional naming strategy, which does not convey information about the component, the factors were named according to a suggestion by Dien (2009), using the relevant temporal (i.e. peak latency) and spatial (i.e. peak channel) information. For example, the factor, '500oz' would refer to a factor that peaked 500 ms after picture onset and was maximal at the midline occipital recording site.

The seven factor scores of interest were submitted to a 2 (description type: neutral, negative) × 2 (picture type: neutral, unpleasant) repeated-measures ANOVA (using a Bonferroni-corrected significance level of $P = 0.05/7 = 0.007$). Three of these factors did not differentiate picture or description type. These were: an occipital negativity that resembled the early posterior negativity (EPN; e.g. Schupp *et al.*, 2006; Foti *et al.*, 2009) but did not vary for picture type ($P > 0.45$), description type ($P > 0.82$) or the interaction between picture and description type ($P > 0.29$); early occipital and late parieto-occipital positivities that were consistent with prior work on the LPP (Foti *et al.*, 2009), yet were not sensitive to the effect of picture type ($P > 0.67$ and > 0.50, respectively), description type ($P > 0.10$ and $> .26$, respectively) or the interaction ($P > 0.60$ and > 0.74, respectively). Table 2 presents the results of the significant main effects for the four factors that differentiated picture or description type; Table 3 presents mean amplitudes and standard deviations by condition for each of the four factors that differentiated picture or description type. Figure 2 presents the spatial distribution of voltage differences (i.e. topographic maps, in μV, Figure 2, left) and the factor waveforms (Figure 2, right) for these factors.

The results of the PCA can be grouped into three factors that were sensitive to the effect of picture type and one that was sensitive to the effect of reappraisal frame (Table 2). Centrally maximal positivities at early- (359 ms), mid- (1074 ms) and late- (2436 ms) latencies were larger for unpleasant compared to neutral pictures. A mid-latency (1074 ms) occipital positivity was larger for negatively than neutrally framed pictures.

As shown in Figure 2a, the earliest factor sensitive to the effect of picture type resembled the P300 (e.g. Johnson, 1993; Keil *et al.*, 2002). This component was more positive for unpleasant compared to neutral pictures, but was not sensitive to the effect of prior framing, or the interaction between frame and picture type (Table 2). A mid-latency central positivity (Figure 2b) and a late-latency central factor (Figure 2c), consistent with past research on the LPP (e.g. Cuthbert *et al.*, 2000; Hajcak *et al.*, 2007; Foti *et al.*, 2009; MacNamara *et al.*, 2009), were also sensitive to the effect of picture type. Again, unpleasant pictures elicited larger positivities than neutral pictures. Neither of these factors were sensitive to the effect of frame type or to the interaction between frame and picture type (Table 2).

Another factor that peaked at 1074 ms (Figure 2d) was largest at occipital sites (e.g. Foti *et al.*, 2009; Hajcak and Dennis, 2009). This positivity was sensitive to the effect of frame type (Figure 2d): negative frames elicited larger (more positive) amplitudes than neutral frames. This factor was not sensitive to picture type or the interaction between picture type and frame type (Table 2).

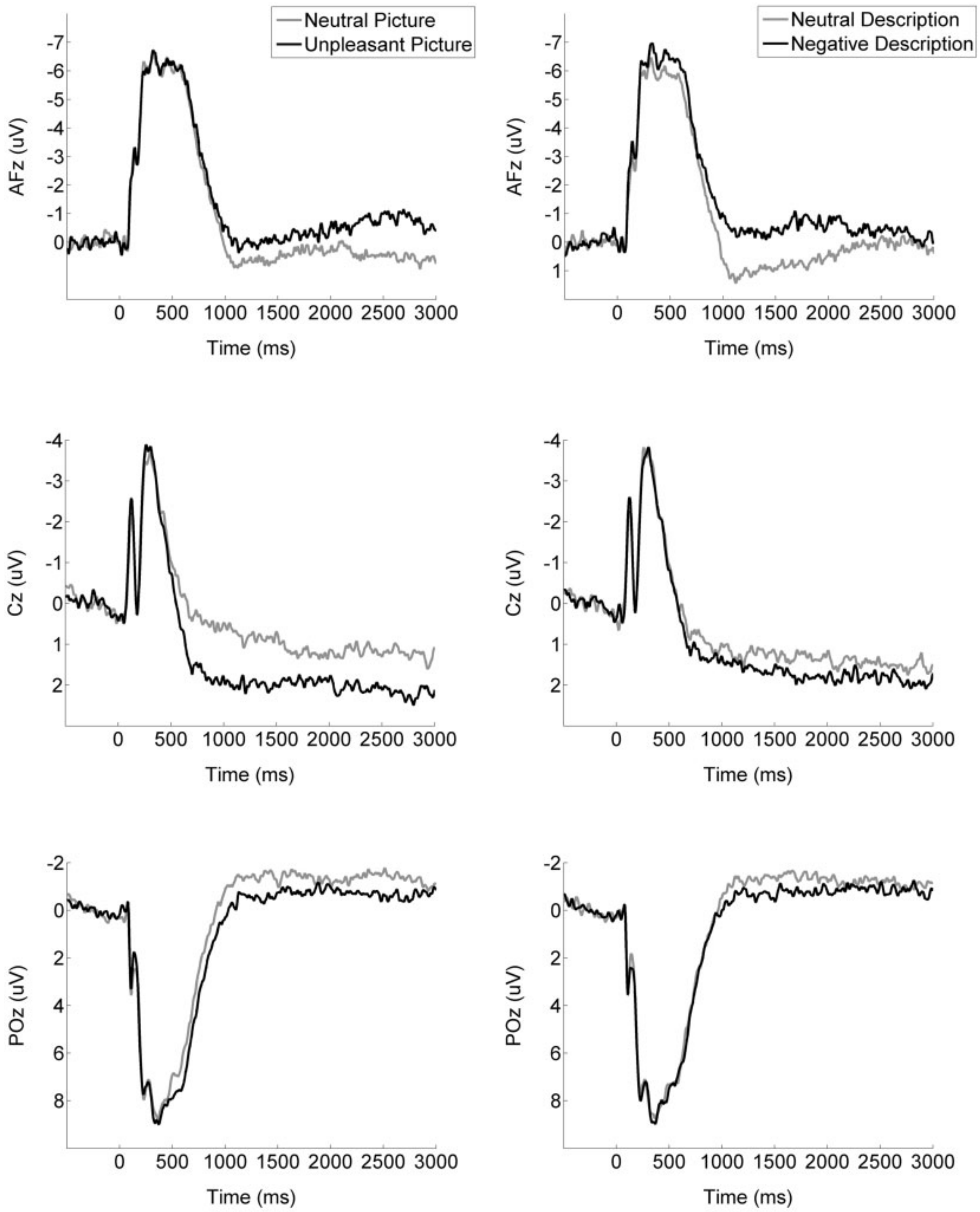

Fig. 1 Grand average waveforms (in μV) for neutral and unpleasant pictures collapsed across description type (left) and for negative and neutral descriptions collapsed across picture type (right) at AFz (top row), Cz (middle row) and POz (bottom row).

Table 2 ANOVA results for temporospatial factors

Temporospatial factor	Spatial distribution	Main effect of description type F (η_p^2)	Main effect of picture type F (η_p^2)	Description × picture type F
359cz	Central positivity	<1 ns	19.41** (0.42)	<1 ns
1074cz	Central positivity	<1 ns	33.86*** (0.56)	3.29 ns
2436cz	Central positivity	2.38 ns	19.04** (0.41)	1.15 ns
1074oz	Occipital positivity	11.41* (0.30)	1.08 ns	<1 ns

F df = (1,27). *$P < 0.005$; **$P < 0.001$; ***$P < 0.00001$.

Table 3 Mean amplitude (and standard deviations) at peak channels for temporospatial factors according to picture and description type

Picture type	Description type	359cz	1074cz	2436cz	1074oz
Neutral	Neutral	0.31 (1.64)	0.33 (1.48)	0.36 (1.53)	−1.00 (3.27)
	Negative	0.26 (1.69)	0.86 (1.35)	0.26 (1.81)	0.36 (3.34)
Unpleasant	Neutral	0.81 (1.84)	1.71 (1.67)	1.24 (1.70)	−0.41 (2.90)
	Negative	0.71 (1.81)	1.44 (1.82)	0.72 (1.81)	0.51 (3.96)

Correlations between self-report ratings and PCA factors

In order to determine whether the effect of picture type on self-report ratings of valence and arousal was associated with corresponding effects on PCA factor scores, difference scores were calculated for unpleasant minus neutral pictures for neutral and negative description types. This was done separately for arousal and valence ratings and for each PCA factor.

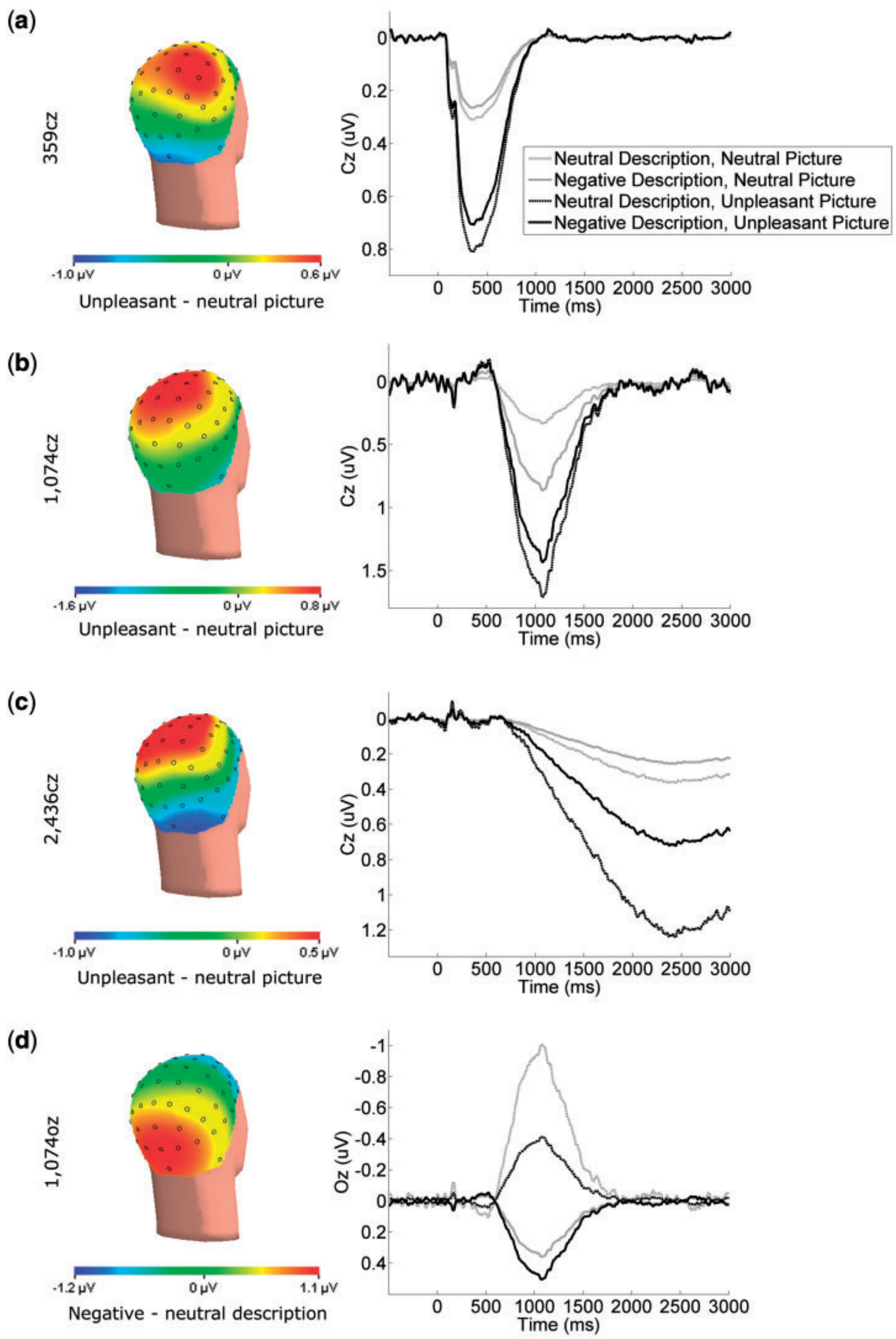

Fig. 2 PCA results for temporospatial factors sensitive the effects of picture type: (**a**) 359cz; (**b**) 1074cz; (**c**) 2436cz; and description type: (**d**) 1074oz. Topographic maps show spatial distributions of amplitude (in μV) for main effects—the mean amplitudes for the difference between negative and neutral descriptions; unpleasant and neutral pictures appear on the left. On the right, factor waveforms (in μV) are presented for each of the four conditions.

Bivariate correlations were then performed between corresponding difference scores for self-report ratings and each PCA factor. The effect of picture type on valence ratings was correlated with the effect of picture type on the mid-latency central positivity (peaking at 1074 ms) when descriptions were neutral $r(28) = 0.38$, $P < 0.05$, such that more unpleasant valence ratings were associated with a larger LPP. Likewise, larger late-latency central positivities (peaking at 2436 ms) to unpleasant compared with neutral pictures were also associated with more unpleasant valence ratings for unpleasant compared to neutral pictures, when descriptions were neutral $r(28) = 0.43$, $P < 0.05$. No other correlations were significant (all P's > 0.11).

Next, to determine whether the effect of reappraisal frame on PCA factor scores corresponded to self-report ratings of valence and arousal, difference scores were calculated for negative compared to neutral descriptions for unpleasant and neutral pictures separately. Correlations between the effect of reappraisal frame on self-report ratings and PCA factor scores did not reach significance (all P's > 0.15).

DISCUSSION

This study posed the novel question of whether the effects of reappraisal persist when stimuli are re-encountered. Overall, the results suggest that reappraisal-related changes in meaning were capable of modulating neural and subjective response to pictures encountered ~30 min later. Three types of key findings were observed.

ERP response to pictures

Three centrally distributed PCA factors were sensitive to the type of picture presented, and were consistent with previous research on the LPP (Cuthbert *et al.*, 2000; Hajcak *et al.*, 2007; Foti and Hajcak, 2008; Hajcak and Olvet, 2008; Pastor *et al.*, 2008; Foti *et al.*, 2009), The earliest of these factors peaked 359 ms following picture onset, and corresponded to previous work on the P300/early LPP (e.g. Lifshitz, 1966; Radilová, 1982; Johnston *et al.*, 1986; Johnson, 1993; Keil *et al.*, 2002; Foti *et al.*, 2009;). Two later factors peaked at 1074 and 2436 ms following picture onset and corresponded to the mid- and late-latency portions of the LPP, respectively (e.g. Cuthbert *et al.*, 2000; Foti *et al.*, 2009). All three of these centrally-distributed factors were larger for unpleasant compared to neutral pictures (in line with previous work: Schupp *et al.*, 2000; Hajcak *et al.*, 2007; Hajcak and Olvet, 2008; Pastor *et al.*, 2008; MacNamara *et al.*, 2009). Thus, throughout picture presentation, unpleasant pictures elicited increased positive potentials that index sustained attention to emotional stimuli (Schupp *et al.*, 2006; Olofsson *et al.*, 2008). None of these centrally-distributed factors were sensitive to the effect of description type or the interaction between description and picture type.

ERP response to reappraisal frames

Second, pictures that had previously been framed negatively were associated with a mid-latency occipital positivity that peaked 1074 ms following picture onset. This positivity corresponded to a prior PCA factor identified during picture viewing (Foti *et al.*, 2009) and was larger for negatively framed pictures.

In previous work, reappraisal frames were presented immediately before pictures—and modulated multiple midline PCA factors, as early as 330 ms following picture onset (MacNamara *et al.*, 2009). In contrast, the effect of reappraisal frames in the current study was evident in fewer and later PCA factors. Meaning change may elicit a less widespread electrocortical effect as time passes. It is also possible that frontal activity observed in prior work could reflect, in part, the 'process' of reappraising—including the integration of frames with pictures. This would be consistent with prior work linking frontal activation to the top–down modulation of emotion (e.g. Ochsner *et al.*, 2002; Goldin *et al.*, 2008; Ochsner and Gross, 2008; McRae *et al.*, 2010). By contrast, frontal effects may be absent in the current study because participants were required to recall, but not actively integrate, reappraisal frames and pictures. Similarly, the relatively later impact of reappraisal frame on ERP activity in the current study could be due to the fact that participants needed to identify picture content before the description previously associated with that picture could be activated in memory.

Self-report and correspondence with ERP data

Reappraisal also had a lasting effect on self-report ratings of pictures. Both unpleasant pictures and pictures that had been described more negatively were rated as more arousing and more unpleasant than neutral pictures and pictures that had been described more neutrally, respectively. In line with previous work, description type affected self-report ratings more for neutral than unpleasant pictures (MacNamara *et al.*, 2009). Thus, it appears that self-reported measures of emotion are more malleable in response to neutral stimuli, at least with the types of reappraisal frames used here.

Compared to previous work in which ratings were obtained immediately after the initial encounter with reappraisal frames (MacNamara *et al.*, 2009), differences in self-report ratings as a function of frames were smaller in the present study for arousal, but not valence. These results suggest that the effect of reappraisal may diminish somewhat over time—at least for *arousal* ratings; reappraisal may have more lasting effects on measures of valence.

The effect of picture type on valence ratings was associated with larger mid- and late-latency PCA factors when reappraisal frames were neutral; there were no significant correlations between frame type and self-report measures of valence or arousal. Although reappraisal frames had had a greater effect on self-reported responses to neutral than unpleasant pictures, a similar pattern was not observed in any

PCA factor. It is therefore unclear what neural process accounts for the differential effect of framing on subjective emotional experience.

The LPP correlates with self-report ratings in some studies (Hajcak and Nieuwenhuis, 2006) but not others (Foti and Hajcak, 2008; MacNamara *et al.*, 2009). A variety of factors—such as subjective awareness of emotional response as well as willingness and ability to accurately report this emotional response—may increase variability in self-report ratings and reduce correlations with the LPP. Across studies, however, the overall pattern of data suggests that larger electrocortical positivities are elicited by more unpleasant and more arousing pictures—even when the *magnitude* of the LPP is not predicted precisely by self-report.

Future directions

Future work could facilitate a more direct comparison of the immediate and delayed effects of reappraisal by repeating the current design and recording ERPs at both initial and subsequent stimuli presentations. Adding a group that viewed the pictures for the second time immediately after the initial presentation of frames and pictures would also help separate the effects of time from the repeated presentation of stimuli (i.e. in the present study these effects are confounded because both frames and pictures were presented initially but only pictures were presented 30 min later).

It will also be important to determine whether other emotion regulatory strategies, such as suppression and distraction, might have similarly long-lasting effects as reappraisal. These techniques have been compared to each other and to cognitive reappraisal in terms of their cognitive and emotional consequences (e.g. Gross, 1998; Richards and Gross, 2000; McRae *et al.*, 2010), however, the *persistence* of these effects on neural response to subsequent presentations of stimuli has not been examined (but see Kross and Ayduk, 2008 for a comparison of the persistence of distancing, immersion and distraction techniques). In addition, it will be important to determine whether *self-generated* reappraisals might evoke similarly prolonged effects as observed in the present study which used descriptions.

Another strategy that modulates response to emotional pictures is attentional deployment: work by Dunning and Hajcak (2009) and Hajcak *et al.*, (2009) showed that the LPP was decreased when participants attended to less emotional compared to more emotional *parts of pictures*. Although the present results were interpreted as evidence that reappraisals evoked lasting *meaning* change, one possibility is that attentional deployment explains some of this effect. For example, it is possible that frame type modulated where participants looked and for how long (van Reekum *et al.*, 2007). Future work could use eye-tracking to measure differences in visual attention as a function of frame type and the relationship between looking-time and ERP and self-report measures following a delay.

A third question is whether the effects of cognitive reappraisal can persist over longer delays than were studied here. Cognitive behavior therapy uses cognitive reappraisal to help clients alter the way they perceive emotional events (Beck, 1979), however, it is not clear how long the effects of reappraisal may last. A better understanding of the temporal limitations of reappraisal could lead to better treatment models (e.g. teaching clients specific strategies for dealing with the potential decay of reappraisal effects across time). In addition, it is presently unclear whether the duration of reappraisal effects depends on explicit memory of reappraisals, or whether, once reappraised, emotional stimuli are processed differently during subsequent encounters without explicit recall of reappraisals. With important implications for clinical work, this issue could be examined in the future by testing for implicit and explicit memory of reappraisals at the time of the second picture presentation.

Finally, it is unclear how long reappraisal lasts in clinical populations. It may be, for example, that the effects of reappraisal are less durable for individuals who are depressed or who are high in anxiety. Previous work suggests that anxiety may be associated with greater difficulty in selecting and enacting emotion regulation strategies (e.g. Salovey *et al.*, 2002; Salters-Pedneault *et al.*, 2006), which could lead to reappraisals that are relatively short-lived.

The present results suggest that changes to the way in which pictorial stimuli are framed can have lasting effects on the subjective and neural responses they elicit. By providing new learning experiences and restructuring appraisals of emotional stimuli, cognitive and behavioral therapies seek to create lasting change in the way in which emotional stimuli are processed. While it is not clear whether the changes evoked by cognitive therapies are mechanistically identical to reappraisal frames, both involve manipulation of implicit or explicit meaning and possible changes in attentional allocation. The current study provides experimental evidence of the durability of reappraisals and lays the groundwork for future investigations in this regard.

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