Article

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KORB, Sebastian, *et al*.

Abstract

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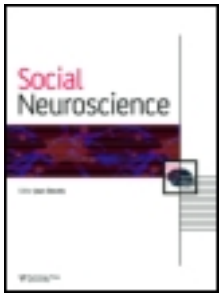

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The neurophysiological study of emotion regulation focused on the strategy of reappraisal—i.e., the cognitive reinterpretation of a stimulus. Reappraisal reduces emotional expression, the experience of both negative and positive feelings, and the amplitude of an event-related potential (ERP)—the late positive potential (LPP). In contrast, the strategy of expressive suppression (ES), being the inhibition of emotional expression, has been reported to reduce subjective feelings of positive, but not negative emotion, and has not yet been investigated with ERPs. We focused on the LPP to assess the correlates of ES in the context of humor perception. Twenty-two female participants rated sequences of humorous (H) and non-humorous (NH) pictures, while their zygomaticus muscle was recorded. A spontaneous (SP) condition, in which participants attended naturally to the pictures, resulted in higher ratings of funniness, increased smiling, and increased LPP amplitude for H compared to NH stimuli. An ES condition, in which participants suppressed their facial reactions, resulted in reduced smiling, without affecting subjective ratings. LPP amplitude did not differ between H and NH stimuli during ES, suggesting equal allocation of processing resources to both stimuli. These results suggest that, similarly to reappraisal, ES modifies the way the brain processes positive emotional stimuli.

Keywords: Emotion regulation; Expressive suppression; Humor; EEG; EMG.

Reappraisal, i.e., the cognitive reinterpretation of a situation's meaning, can—depending on the person's intent—diminish or augment felt positive or negative emotions (Ochsner & Gross, 2008). Simultaneously, reappraisal leads to the reduction or the increase of a brain wave—the late positive potential (LPP)—which is thought to reflect the amount of attention and processing resources that a person is allocating to a stimulus or situation (Hajcak, MacNamara, & Olvet, 2010). Similarly, when viewing negative scenes, both one's felt emotions and one's LPP size decrease with distraction (Thiruchselvam, Blechert, Sheppes, Rydstrom, & Gross, 2011). Far less is known, however, about the subjective effects and neurophysiological correlates of another emotion regulation strategy—expressive suppression (ES). It has been claimed that ES can only diminish one's amusement and positive feelings—and has no effect upon negative feelings (Gross & Levenson, 1997). However, this has not been confirmed by all studies to date (Zuckerman, Klorman, Larrance, & Spiegel, 1981). Finally, ES has not yet been investigated with ERPs, and thus it remains unknown whether it can modulate LPP amplitude. Given the importance of understanding the neural processes and psychological effects of the emotion-regulation strategies, and in light of the fact that humor might be not only an exceptional target for ES but also a potent strategy for emotion regulation on its

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own (Samson & Gross, 2012), we carried out the experiment presented here.

Humans have the extraordinary capacity to voluntarily modulate their reactions to emotional stimuli and situations, thus increasing the flexibility of their behavior, and allowing them to adapt to new situations and conform to societal rules and norms. Emotion-regulation capacities build up during infancy, and their impairment may lead to impulsive, aggressive, and violent behavior (Davidson, Putnam, & Larson, 2000), and to the formation of psychiatric disorders (Phillips, Ladouceur, & Drevets, 2008; Taylor & Liberzon, 2007). The study of emotion regulation, which has long been confined to work on psychological defenses, stress, coping, and self-regulation (Ochsner & Gross, 2005), has recently started to use psychophysiological and neuroimaging techniques. It was found that reappraisal—i.e., the cognitive reinterpretation of the meaning and outcomes of emotional stimuli—can lead to decreased or increased subjective feelings of emotion, and operates through the down- or up-regulation of limbic areas (e.g., amygdala, insula) via prefrontal structures (e.g., dorso-lateral, ventro-lateral, and ventro-medial prefrontal cortex; Diekhof, Geier, Falkai, & Gruber, 2011; Ochsner & Gross, 2007, 2008). Another form of emotion regulation is expressive suppression (ES), referring to people's ability to voluntarily suppress their expressive behavior in reaction to emotional stimuli, but without trying to reinterpret the stimulus' meaning (as in reappraisal). According to Gross and Levenson (1993), ES reduces considerably the amount of emotional expression shown in a person's facial and bodily movements, leads to a general activity increase of sympathetic nervous system activity, but has little impact on the person's subjective experience of emotions. The exception to this rule may be found in the case of humor perception, as ES has been reported to be effective in reducing one's subjective feelings of amusement (Gross & Levenson, 1997; Soussignan, 2002; Strack, Martin, & Stepper, 1988; for a review, see also Demaree, Robinson, Everhart, & Schmeichel, 2004) and positive emotions in general (Vrticka, Sander, & Vuilleumier, 2011). However, Zuckermann, Klorman, Larrance, and Spiegel (1981) did not find reduced feelings of amusement during ES. Thus, to date, uncertainty remains about whether, and under which circumstances, ES can reduce subjective feelings of emotion. It is therefore imperative to clarify the psychological mechanisms and neural processes underlying different strategies (and different contexts) of voluntary emotion regulation, as a healthy and psychologically balanced person should be able to choose, in a flexible and adaptive way, the most appropriate regulation strategy for each context (Bonanno, Papa, Lalande, Westphal, & Coifman, 2004; Westphal & Bonanno, 2004).

However, the neural bases of ES remain understudied. Goldin, McRae, Ramel, and Gross (2008) have published the first fMRI study investigating the neural bases of ES.[1] Their results revealed that both reappraisal and ES of disgust activate prefrontal regulation areas, but at different latencies—i.e., reappraisal between zero and 4.5 s, and ES between 10.5 and 15 s after stimulus onset. Moreover, activity in the emotion-related amygdala and insula was decreased with reappraisal, but increased with ES. These results are in line with Gross' model, which posits reappraisal as an antecedent-focused, and ES as a response-focused emotion-regulation strategy (Gross, 2002). A more recent study, using a block design and short stimulus presentation times, compared the neural correlates of reappraisal and ES to pictures from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 1999) with positive and negative valence, and with social or non-social content (Vrticka et al., 2011). The results showed that the superior and middle frontal gyri were more activated by the reappraisal strategy, while the superior frontal sulcus and supplementary motor area were more engaged by ES. Moreover, reappraisal was found to modulate the activity of the left amygdala, while ES affected more the right-sided amygdala.

Researchers have recently started to investigate the neural bases of emotion-regulation strategies by using event-related potentials (ERPs). Reappraisal was found to modulate the amplitude of the LPP (for a review, see Hajcak et al., 2010). The LPP is an electrophysiological wave with positive polarity over centro-parietal sensors, starting around 300 ms after stimulus onset and lasting for up to several hundreds of milliseconds. The LPP is increased for the perception of emotional compared to neutral stimuli, and may reflect increased allocation of attention and processing resources (Cacioppo, Crites, Berntson, & Coles, 1993; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Olofsson, Nordin, Sequeira, & Polich, 2008). This boosted processing of emotional stimuli has been suggested to be independent of competing task demands (Hajcak, Dunning, & Foti, 2007; but see MacNamara, Ferri, & Hajcak, 2011; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). The finding that LPP amplitude can be modulated through reappraisal has led to the proposition that it may constitute a neurophysiological

[1] Other studies investigating ES in fact instructed their participants to suppress not only their emotional expression but also their subjective feelings (e.g., Levesque et al., 2003; Ohira et al., 2006).

marker of emotion regulation (Hajcak & Nieuwenhuis, 2006; Moser, Hajcak, Bukay, & Simons, 2006; Moser, Krompinger, Dietz, & Simons, 2009).

In one of the first ERP studies on emotion regulation, Moser et al. (2006) presented neutral and unpleasant pictures of the IAPS (Lang et al., 1999) in three conditions. A view condition served as baseline, to which a suppress and an enhance condition were compared. Importantly, both the suppress and enhance conditions required a cognitive reinterpretation of the stimulus (the word *suppress* is somewhat misleading here). The results showed that the amplitude of the LPP, measured between 350 and 600 ms after stimulus onset (SO) over the parietal electrode Pz, was increased for emotional compared to neutral pictures in the view condition, and was decreased for negative pictures in the suppress condition, compared to the view condition. The amplitude of the LPP for negative pictures in the enhance condition did not differ from the one in the view condition. However, modulation of the LPP in response to unpleasant pictures was found, in a subsequent study, in the direction of emotional intensity—i.e., both for increase and decrease of the emotional response through reappraisal (Moser et al., 2009). Moreover, reappraisal was shown to decrease the LPP amplitude not only for unpleasant, but also for pleasant, pictures (Krompinger, Moser, & Simons, 2008). These and further recent studies have demonstrated that the LPP in reaction to negative and positive pictures can reliably be decreased, and sometimes increased, through cognitive reappraisal (for a review, see Hajcak et al., 2010). Finally, distraction—a further emotion regulation strategy— was also shown to reduce the amplitude of the LPP (Thiruchselvam et al., 2011). However, no ERP study has yet investigated the neural bases of ES, as defined by Gross and colleagues (Gross & Levenson, 1993; Gross & Thompson, 2007).

In the experiment presented here, we used humorous (H) visual stimuli, to elicit amusement and positive emotions. We decided to use H stimuli because previous studies suggested that ES does not modify subjective feelings of negative emotions (Gross & Levenson, 1993; Vrticka et al., 2011), but that ES can reduce subjective feelings of amusement and positive emotions (Gross & Levenson, 1997; Soussignan, 2002; Strack, Martin, & Stepper, 1988; Vrticka et al., 2011; but for inconsistent results, see Zuckermann et al., 1981).

Although *H* stimuli may elicit positive emotions in ways comparable to non-humorous (NH) pleasant pictures, they also represent a class on their own. Indeed, humor comprehension involves at least two processing stages (Martin, 2007; Ruch, 2007; Suls, 1972). First, an incongruity has to be detected, which has, second, to be meaningfully resolved in a playful way, by recognizing which logical mechanisms the joke is based on—for example, that the punchline is based on analogy or exaggeration (Attardo & Raskin, 1991). Importantly, the playful resolution of the incongruity is characteristically accompanied by a positive emotional state[2] of cheerfulness, amusement, exhilaration, or mirth (Martin, 2007; Ruch, 1993).

Recently, neuroimaging studies have started elucidating, by using jokes, cartoons, or humorous movies, the neural processes underlying humor processing (e.g., Bartolo, Benuzzi, Nocetti, Baraldi, & Nichelli, 2006; Goel & Dolan, 2001; Mobbs, Greicius, Abdel-Azim, Menon, & Reiss, 2003; Samson, Hempelmann, Huber, & Zysset, 2009; Samson, Zysset, & Huber, 2008). Results suggest that cognitive humor processing involves, mainly in the left hemisphere, the temporo-parietal junction and adjacent areas, the temporal pole, and the inferior frontal gyrus (IFG). Increased activations in response to humor have also been reported in the supplementary motor area (SMA), as well as in several subcortical areas (Mobbs et al., 2003). Variability in the neuroimaging results may depend on the precise cognitive sub-processes involved, and on the type of humor being processed (Samson et al., 2008, 2009).

As humor processing entails specific cognitive processes, one has to ask whether ERPs evoked by the perception of humorous pictures may differ from those evoked by non-humorous emotional pictures (e.g., IAPS). Unfortunately, past studies addressing humor processing with ERPs used almost exclusively verbal stimuli (jokes), and focused mainly on physiological indexes of lexical integration, such as the N400 component—a wave with negative polarity and approximate latency of 400 ms (Bandettini, Gillikin, Bartolome-Rull, & Bogart, 1997; Coulson & Kutas, 2001; Coulson & Lovett, 2004; Coulson & Severens, 2007; Coulson & Williams, 2005; Coulson & Wu, 2005). To the best of our knowledge, so far, a study by Gierych, Milner, and Michalski (2005) is the only one to have investigated humor processing with ERPs and humorous pictures. This study used several visual stimuli of different kinds—famous cartoon characters, household objects, pictures reminiscent of a previously presented joke, related pictures but without such an association, heavily distorted humorous caricatures, and line drawings—presented as targets or non-targets in an oddball-like task. The authors reported increased ERPs for H compared to NH stimuli from 200 to 580 ms, with variations by stimulus class, electrode,

[2] Mirth, exhilaration, and amusement are often used interchangeably in the humor literature and designate the positive response to humorous stimuli.

and task. Positive waves at 300 and 400 ms, reminiscent of the P3b and the LPP components, were present, and their amplitudes generally increased for humorous compared to neutral pictures. Interestingly, this study suggests that although the perception of humorous pictures includes partly different cognitive processes from those accompanying the perception of non-humorous emotional pictures, both types of stimuli recruit greater attentional and processing resources (reflected in a larger LPP) than non-humorous neutral pictures.

Previous research has shown that emotional reactions to H stimuli can—similarly to reactions to NH emotional stimuli—be increased and decreased through reappraisal (Giuliani, McRae, & Gross, 2008). Moreover, ES has been found to reduce self-reported amusement when carried out while watching amusing films (Gross & Levenson, 1997). Humor can also be used as an emotion-regulation strategy on its own (e.g., Samson & Gross, 2012). Importantly, exploring the neural bases of humor perception and of emotion regulation in response to (or via) humor may be of clinical relevance and contribute to the successful treatment of disorders involving alterations in humor perception and humor regulation.

The absence of studies investigating ERPs related to ES, the paucity of ERP studies investigating the processing of H visual stimuli, and finally the fact that not all previous studies found an effect of ES on the subjective feelings of amusement, motivated the experiment presented here. In a spontaneous (SP) condition, participants were instructed to freely watch, rate the funniness of, and feel free to react to H and NH stimuli. In an ES condition, they were instructed to watch and rate H and NH stimuli while suppressing their facial reactions, but without attempting to reinterpret the meaning of the stimuli. Humorous instead of positive IAPS pictures were used because we were specifically interested in the effects of ES upon feelings of amusement, and because zygomaticus contractions in response to positive IAPS pictures have been found to be less reliable than corrugator contractions in response to negative IAPS pictures (Larsen, Norris, & Cacioppo, 2003). Moreover, positive IAPS pictures often contain representations of faces with positive expressions, which could elicit facial mimicry (Korb, Grandjean, & Scherer, 2010), and thus interfere with humor-related smiling. Facial expressions were captured via electromyography (EMG), providing a fine measure of peripheral emotional expression. The subjective experience of amusement was captured via participants' ratings of the stimuli. There were thus four subconditions: spontaneous humorous (SP-H), spontaneous non-humorous (SP-NH), expressive suppression humorous (ES-H), and expressive suppression non-humorous (ES-NH). H and NH trials were selected based on each participant's subjective ratings.

Based on previous reports that participants can successfully inhibit their facial and bodily movement during ES (Gross & Levenson, 1993, 1997; Zuckermann et al., 1981), we expected to find a reduction in smiling in the ES condition compared to the SP condition. Due to the inconsistent research findings in the literature on whether or not ES reduces subjective feelings of emotions, we did not have a specific hypothesis concerning participants' ratings of funniness in the ES compared to the SP condition (Gross & Levenson, 1997; Zuckermann et al., 1981). Based on reports of increased LPP amplitude for H (Gierych et al., 2005), as well as NH but emotionally arousing visual stimuli (Schupp et al., 2000), we hypothesized that H stimuli would elicit a larger LPP amplitude than NH stimuli in the SP condition. Finally, based on previous studies suggesting that both reappraisal and distraction reduce the size of the LPP to both positive (but NH) and negative emotional stimuli (Hajcak et al., 2010, Thiruchselvam et al., 2011), we expected the LPP amplitude to H stimuli to be reduced during ES. Increases in LPP amplitude may indeed stand for increased attention to and processing of emotional stimuli (Cacioppo et al., 1993; Cuthbert et al., 2000; Olofsson et al., 2008).

METHOD

Participants

Twenty-four first- and second-year female psychology students at the University of Geneva, aged between 18 and 35 years ($M = 23$, $SD = 4.4$), with normal or corrected to normal vision, participated in the experiment in exchange for course credits and in agreement with local ethical standards. Only female participants were included, as they generally show greater emotional reactivity (Dimberg & Lundquist, 1990; Grossman & Wood, 1993). Two participants were excluded for extreme ratings (see Data analysis section).

Stimuli

Three hundred pairs of pictures were created by collecting H (i.e., emotionally positive) and NH (i.e., emotionally neutral) pictures from the Internet and modifying them with Photoshop (Adobe Systems Incorporated, San Jose, CA, USA). Each trial included one pair of pictures. The first picture was always NH, and the second picture always introduced a slight

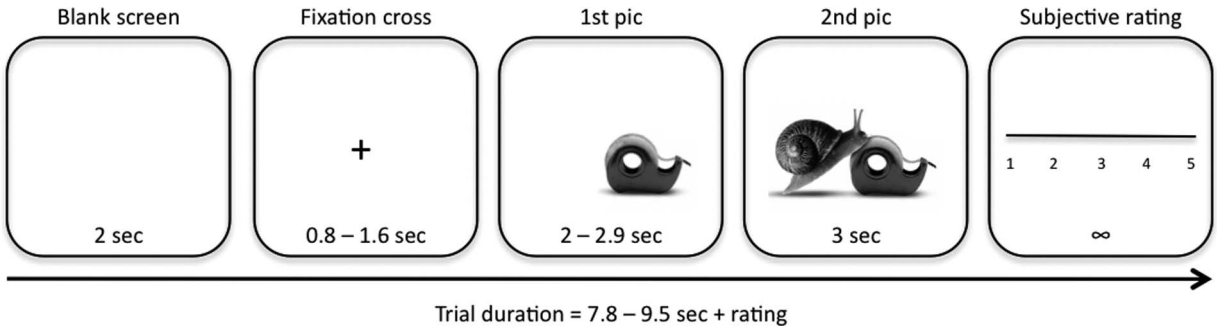

Figure 1. Sequence of elements included in each trial. The first picture was always neutral, while the second picture was either humorous (H), or non-humorous (NH).

change (i.e., a new element appeared, or an element of the first picture disappeared), making the trial H or keeping it NH (for a study using similar stimuli, see Schwartz et al., 2008). A rating study with 50 participants who did not take part in the main experiment, carried out before the actual experiment, allowed us to verify that approximately half of the trials were generally perceived as H, and the other half as NH.[3] All pictures during the experiment were in grayscale, with a size of 9.23 by 9.23 cm, and covered 8.2 × 8.2° of visual angle. They did not contain written text or depictions of facial expressions of emotion, in order not to cause linguistic processing or trigger facial mimicry. The assignment of each stimulus to either experimental condition (see below) was randomized across participants.

Procedure

Participants gave written consent, had electrodes attached for electroencephalography (EEG) and EMG recording (see below), and were seated in a comfortable chair in a dimly lit room, at 1 m distance from a 17-inch computer screen. Participants watched a pair of related pictures per trial. More precisely, each trial included, in the following order (see Figure 1): a blank screen for 2 s, a central fixation cross for 1.2 s on average (range 0.8 to 1.6 s), the first picture of the pair (always NH) for 2.5 s on average (range 2 to 2.9 s), the second picture (H or NH) with a fixed duration of 3 s, and finally a rating screen that stayed on until the participant's button press. Participants rated how amusing they found the preceding pair of pictures on a 5-point Likert scale (1 = absolutely not amusing, 2 = not amusing, 3 = a little amusing, 4 = amusing, and 5 = very amusing). Emotion regulation was manipulated as follows: In a spontaneous (SP) condition, participants were free to express their emotional facial reactions to the stimuli. In an expressive suppression (ES) condition, they were instructed to suppress their facial reactions to the stimuli. Instructions stressed that participants had to concentrate on their facial reactions without modifying their subjective experience of emotion through the reinterpretation of the stimuli (as in reappraisal), thinking of something else, or looking away (from the picture or from humorous elements in it). Each condition included 150 trials, evenly divided into H and NH trials based on ratings of a pilot study (see above). The order of H and NH trials in each condition was semi-random, with no more than three trials of the same type in a row. Order of conditions was counterbalanced across participants. Importantly, each picture appeared, across participants, in both conditions. Thus, analyses comparing the SP and ES condition were carried out on physically identical stimuli.

Electrophysiological recording and data reduction

Using a BIOSEMI (www.biosemi.com) ActiveTwo amplifier system with Ag/AgCl active electrodes, a sampling rate of 2048 Hz and a bandwidth of DC-1.6 kHz, EEG was recorded from 64 scalp

[3] The second picture of each pair was rated in the pilot study on a 100-point visual analog scale ranging from 1 (not at all humorous) to 100 (very humorous). Out of the initial picture set, 294 pictures were retained after removal of outliers. Scores were standardized (this explains partly negative scores) and averaged over participants. A one-way ANOVA with the factor Stimulus Type (two levels: H and NH; these categories were based on an a priori categorization) resulted in a significant main effect: $F(1, 292) = 702.5$, $p < .001$. Humorous trials ($M = 0.59$, $SE = 0.03$) were rated as significantly more humorous than neutral trials ($M = –0.6$, $SE = 0.03$). Finally, six new picture pairs were added for the main experiment, which included 300 picture pairs in total. Note that the rating study only served to confirm that approximately half of the trials were generally perceived as H and the other half as NH. This allowed achievement of an equal distribution of H and NH trials. Analyses of the ERP and EMG data from the main experiment were instead based on each participant's subjective ratings on a 5-point Likert scale.

channels, and facial EMG was recorded, according to guidelines (Fridlund & Cacioppo, 1986) over the left corrugator (used for frowning), the left orbicularis oculi (forming crow's feet around the eyes during smiling), and the left and right zygomatic muscles (raising the corners of the mouth during smiling). Only EMG data of the zygomatic muscles will be reported here.

Off-line, using MATLAB (MathWorks, www.mathworks.com) and the EEGLAB toolbox (Delorme & Makeig, 2004), EEG data were put into average reference, filtered from 0.1 to 30 Hz, down-sampled to 256 Hz, segmented from 250 ms before to 3 s after the onset of the second picture, and baseline corrected with the 250-ms period preceding the onset of the second picture. Artifacts from blinking and eye movements were removed by the independent component analysis (ICA) method proposed by Delorme and Makeig (2004).[4] Defect electrodes were interpolated (mean and *SD* of the number of interpolated electrodes over participants were 1.9 and 1.6, respectively). Trials with amplitudes greater than 100 μV or smaller than –100 μV were removed. Finally, for each participant, the same number of trials ($M = 52$, $SD = 10.6$) was randomly selected over both conditions, further segmented from 250 ms before to 800 ms after onset of the second picture, and averaged for ERPs.

EMG data were put in bipolar montage, filtered between 20 and 400 Hz, down-sampled to 256 Hz, full-wave rectified, smoothed with a sliding average (window size = 5 time frames, or 19.5 ms), and segmented from 250 ms before to 6.5 s after the onset of the first picture, thus comprising the first and the second pictures. Muscular activity present in the 3-s period after the onset of the second picture was assessed as follows:

1. For each participant and for both the right and left zygomatic muscles, we excluded trials where the average amplitude of the muscle, in the period from 250 ms before the onset of the first picture up to the onset of the second picture, exceeded by more than 2 *SD*s the average amplitude over all the trials of all the conditions in the same period (average and *SD* of excluded trials over the four subconditions were 20.3 and 12.4).
2. EMG onsets were defined as the earliest time frame (TF), corresponding to 3.9 ms after down-sampling, after the onset of the second picture, where signal amplitude exceeded baseline amplitude (period from 250 ms before the onset of the first picture up to the EMG onset) of the same trial by at least 3 *SD*s, and stayed that high for at least 12 TFs (47 ms).
3. EMG onsets were subsequently checked by visual inspection, and adjusted if required.
4. In order to separate bilateral smiles from unilateral activation, trials comprising EMG activity in both the left and the right zygomaticus muscle were further assigned to the class of "true" smiles if the difference in EMG onsets in the two muscles was below 500 ms, and the mean amplitude in the two muscles after their respective onset was at least two times stronger than the mean amplitude in the period from 250 ms before the onset of the first picture up to the EMG onset.

Data analysis

We started by inspecting participants' rating behavior. Here, a small number of trials was excluded from analyses because of response times (RTs), calculated from the offset of the second picture in each trial, that were under 100 ms or over 3058.56 ms (corresponding to the sample mean plus 3 *SD*s). We computed for each participant the total number of H and NH trials in both conditions, as well as the average and *SD* over all participants. H trials included all trials rated 3 (a little amusing) to 5 (very amusing), while trials with ratings of 1 (absolutely not amusing) and 2 (not amusing) were classed as NH. Two participants were excluded, as their number of H trials was more than 2 *SD*s below the sample mean. All analyses were carried out on the remaining 22 participants. Using dependent-sample two-tailed *t*-tests, ratings were compared across participants by comparing conditions and types of stimuli, and across stimuli by comparing conditions.

For the EMG, differences in the occurrence of true smiles between conditions and stimulus type were tested with dependent-sample, two-tailed *t*-tests. The EMG data from the average onset of the second picture until 3.5 s later (in order to cover the entire length also of trials where the onset of the second picture was at 2.9 s) were averaged over seven windows of 500 ms each—and analyzed in a 2 (Condition: SP, ES) by 2 (Stimulus: H, NH) by 7 (Time) repeated-measures ANOVA. To test whether habituation would lead to a decline in smiling, we assessed the average and median trial number at which

[4] Blinks were identified by their topography with high loadings on bilateral fronto-polar sites, their low-frequency power spectrum, and their transient time-pattern. Artifacts elicited by saccades and lateral eye movements showed an anterior left–right dipole, high power in lower frequencies, and an abrupt (square-like) change in the component time series. Finally, components corresponding to blinks and eye movements were not time-locked to stimulus onset (for examples of corresponding topographies, see Onton, Westerfield, Townsend, & Makeig, 2006; McMenamin et al., 2010).

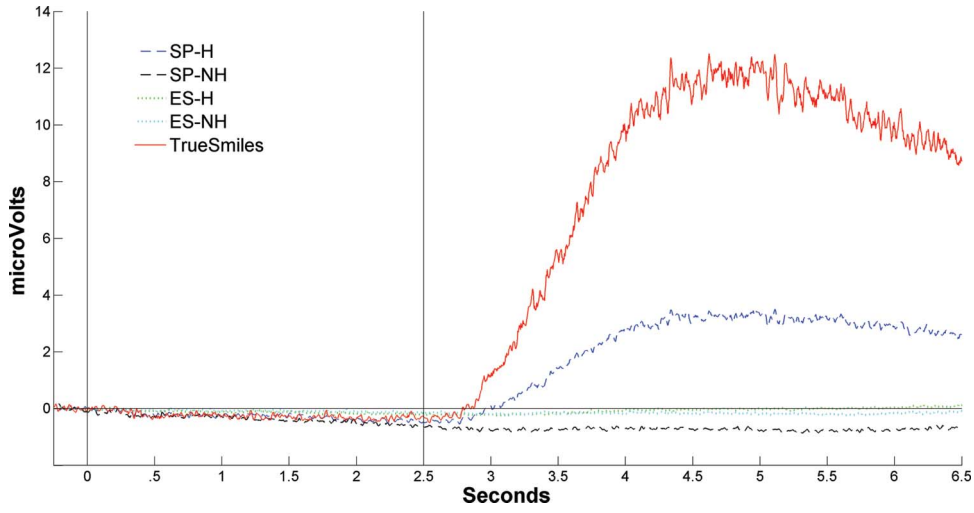

Figure 2. EMG traces (average of left and right zygomatic muscles for all participants, baseline corrected) for all subconditions and during true smiles (red line). Only trials included in the ERP analyses were averaged. Onset of the first stimulus at time 0, average onset of the second stimulus at 2.5 s. SP-H = spontaneous humorous; SP-NH = spontaneous non-humorous; ES-H = expressive suppression humorous; ES-NH = expressive suppression non-humorous; TrueSmiles = strong bilateral smiling (see Method).

true smiles were recorded for each participant in the spontaneous condition, and compared it to the theoretical mean and median trial number.[5]

Four ERPs—one for each trial type—containing an equal number of trials were computed per participant: SP-H, SP-NH, ES-H, and ES-NH. ERPs were checked by visual inspection, and the latency of the components was assessed via automatic peak detection (using Besa software 5.1.8, BESA GmbH, Gräfelfing, Germany) at the electrode where they had maximum amplitude.

Two early components (a posterior positivity peaking over Iz at 27 ms after SO, followed by a posterior negativity peaking over PO8 at 62.5 ms) were identified on the ERP averaged over all four trial types (see Figures 3 and 4). For the two early components and the then following P1 (peaking over PO8 at 105 ms), data were averaged over specific time windows (respectively 12–47 ms, 47–90 ms, and 90–137 ms), which were chosen by visual inspection of the average ERP of all conditions. To test whether these components were affected by the experimental factors, we carried out separate 2 (Condition: SP, ES), by 2 (Stimulus: H, NH) by 64 (Electrodes) repeated-measures ANOVAs. Moreover, we computed 2 (Condition: SP, ES), by 2 (Stimulus: H, NH) repeated-measures ANOVAs at the electrode where each component peaked.

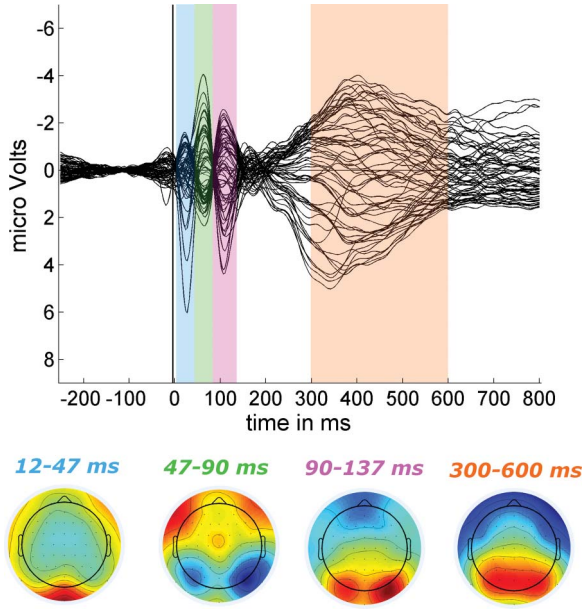

Figure 3. (Top) Average ERP over all trial types. Stimulus onset at time 0. Colored overlays denote time windows for ANOVAs. Area of statistical analyses for the LPP between 300 and 600 ms. (Bottom) Topographies corresponding to the average times indicated by the overlays.

LPP amplitudes were extracted, based on visual data inspection, over 11 parieto-occipital electrodes (P1-4, Pz, POz, PO3-4, Oz, O1-2) from 300 to 600 ms, averaged, and analyzed in a repeated-measures ANOVA with the factors Condition (SP, ES) and Stimulus (H, NH).

[5] After removal of the ES block, the theoretical mean and median trial number corresponded to the number of SP trials after artifact rejection, divided by two. For each participant, the indices of trials at which true smiles occurred were used to calculate the actual mean and median trial numbers, and then compared via dependent-sample, two-tailed *t*-tests to the theoretical values.

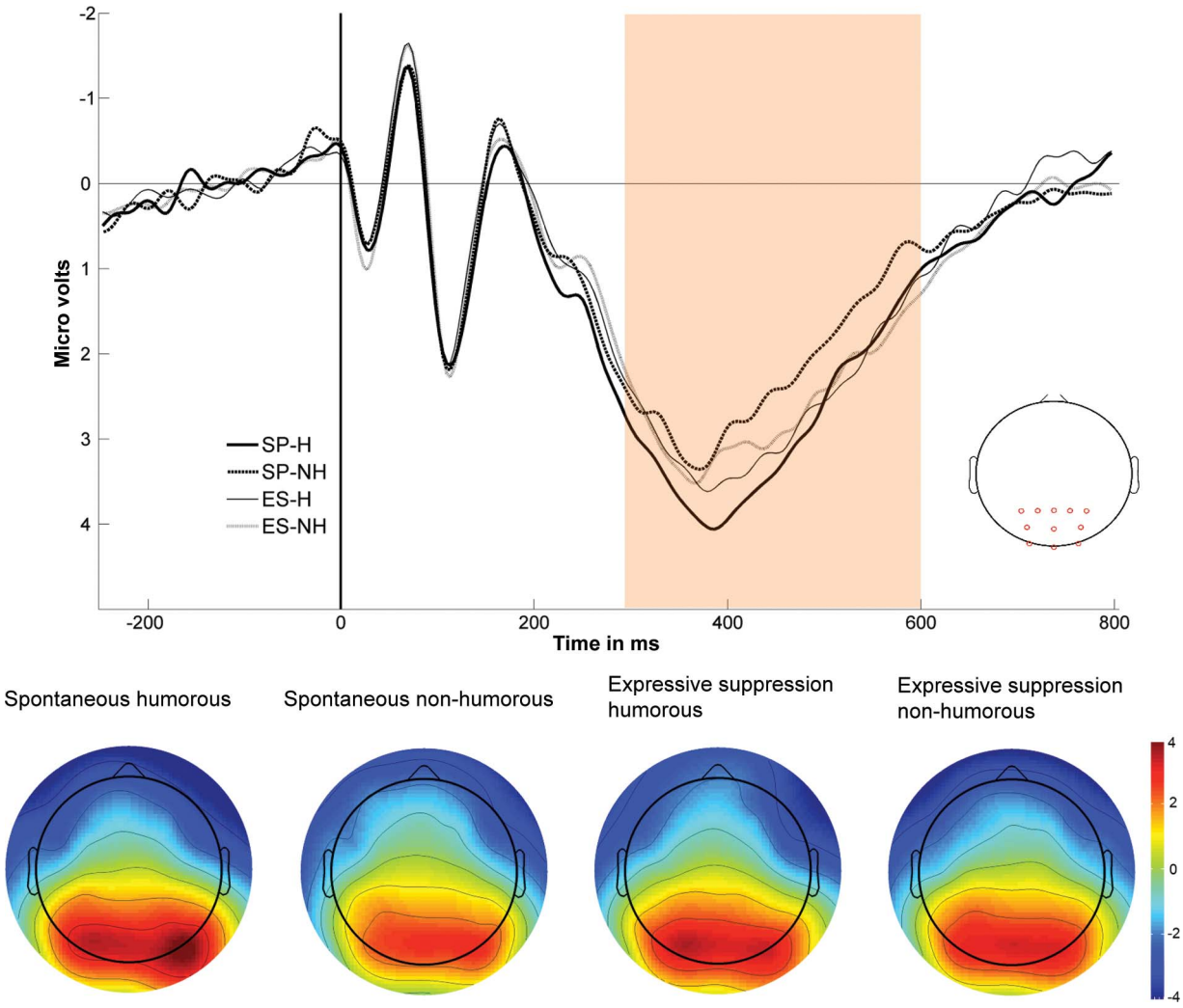

Figure 4. (Top) Activity averaged over 11 posterior electrodes (see locations on transparent head view on the far right) selected for analyzing the LPP. Stimulus onset at 0 ms. LPP analyzed in window from 300–600 ms, indicated by overlay. (Bottom) Topographies for all four trial types during the LPP period.

Statistica 9.0 (www.statsoft.com) served for all statistical analyses. Where needed, sphericity violations underwent Greenhouse–Geisser correction, in which case uncorrected degrees of freedom but corrected p values are reported.

RESULTS

Ratings

The number of H trials ($M = 143.95$, $SD = 19$) and NH trials ($M = 156.05$, $SD = 19.13$) did not differ significantly: $t(21) = 1.48$, $p = ns$. Participants' rating behavior was very consistent, as shown by a high Cronbach's α of .97 across all trials. Amusement ratings given by the participants of the ERP study were in line with those given by the participants in the pilot study. Indeed, trials that had been judged as being amusing in the pilot study (H trials) received, in the ERP study, an average rating of 3.4 ($SD = 0.89$), and neutral trials (NH trials) an average rating of 1.79 ($SD = 0.62$). No differences were found between SP and ES conditions when comparing the average number of trials rated as amusing, $M = 73.6$ and 73.7, $SD = 2.15$ and 1.67, $t(21) = 0.37$, $p = ns$; their average ratings, $M = 3.37$ and 3.44, $SD = 0.87$ and 0.38, $t(21) = 0.98$, $p = ns$, and average RTs in ms, $M = 940.77$ and 953.78, $SD = 271.4$ and 312, $t(21) = 0.27$, $p = ns$, as well as the total (including NH trials) average ratings, $M = 2.58$ and 2.62, $SD = 0.24$ and 0.27, $t(21) = 0.84$, $p = ns$. In comparing conditions across

stimuli, average ratings in the condition SP ($M = 2.58$, $SD = 0.88$) and ES ($M = 2.59$, $SD = 0.91$) did not differ:$t(299) = 0.79$, $p = ns$.

EMG

On average, and across both conditions, true smiling (see Methods section for a definition of true smiling) was specific to feelings of amusement elicited by H trials: it occurred in 10% ($SD = 8.52$) of the H trials, but in only 0.73% ($SD = 1.1$) of the NH trials: $t(21) = 5.03$, $p < .001$. True smiles were not subject to habituation, and appeared in early as well as in later trials of the SP condition. This was shown by the absence of significant differences between the actual and the theoretical mean trial number of appearance of true smiles, $t(21) = 1.55$, $p = .14$, *ns*, and between the actual and the theoretical median trial number of appearance of true smiles, $t(21) = 1.25$, $p = .23$, *ns*. EMG data also showed that participants could successfully suppress their smiling response in the ES condition (see Figure 2). Indeed, true smiling occurred on average in 10% ($M = 15$, $SD = 8.52$) of all the trials in the SP condition, but was basically absent (0.73%, $M = 1.09$, $SD = 1.11$) in the ES condition, $t(21) = 6.37$, $p < .001$. A repeated-measures ANOVA carried out on the EMG data resulted in a main effect of Condition, $F(1, 21) = 16.6$, $p < .001$, with overall greater EMG for SP ($M = 0.8$) than ES trials ($M = –0.1$); a main effect of Stimulus, $F(1, 21) = 17.7$, $p < .001$, due to greater EMG for H ($M = 1.1$) than NH trials ($M = –0.4$); and a main effect of Time, $F(6, 126) = 14.9$, $p < .001$, due to increasing EMG amplitudes from the first ($M = –0.36$) to the fourth ($M = 0.6$) time window. Moreover, we found interaction effects of Condition by Stimulus, $F(1, 21) = 17.7$, $p < .001$, Condition by Time, $F(6, 126) = 15.31$, $p < .001$, Stimulus by Time, $F(1, 21) = 16.7$, $p < .001$, and Condition by Stimulus by Time, $F(6, 126) = 15.8$, $p < .001$. Post-hoc tests showed the following:

1. greater amplitudes for H ($M = 2.36$) than NH trials ($M = –0.7$) in the SP condition only ($p < .001$)
2. greater EMG (all $p < .001$) for the SP than ES condition from the third time window on (1–1.5 s after SO)
3. greater amplitude (all $p < .05$) for H than NH trials from the second time window on (500 ms to 1 s after SO).

For the triple interaction, post-hoc tests showed significantly greater EMG in reaction to H versus NH trials in the SP condition from the second time window onward (all $p < .001$); EMG in reaction to H and NH trials did not differ at any time in the ES condition.

ERPs

Analysis over all 64 electrodes of the first three ERP components resulted in a significant main effect of Electrode (respectively for the first, second, and P1 component: $F(63, 1323) = 9.98, 10.35, 12.95$, $p < .05, < .001, < .001$), but no other main effects or interactions (all $F < 2.2$; all $p > .05$). Similarly, no significant main or interaction effects emerged from the analyses of these components when including solely data from the electrode at which they respectively peaked (all $F < 3.2$, all $p > .05$).

Data inspection showed an LPP peaking over POz at 375 ms (3.36 μV) for H, and at 360 ms (3 μV) for NH trials in the SP condition. In the ES condition, the LPP peaked over POz at 371 ms (3.24 μV) for H, and at 360 ms (3.33 μV) for NH trials. We extracted the average amplitude from 300 to 600 ms after SO over parieto-occipital electrodes (see Methods section and transparent head view on Figure 4), and analyzed it in a repeated-measures ANOVA, resulting in a significant main effect of Stimulus, $F(1, 21) = 4.59$, $p < .05$, and a significant Condition by Stimulus interaction, $F(1, 21) = 7.34$, $p < .05$. The main effect was due to H trials eliciting greater amplitudes ($M = 2.8$, $SD = 1.89$) than NH trials ($M = 2.43$, $SD = 1.69$). The interaction (Figure 5) showed only a significant difference

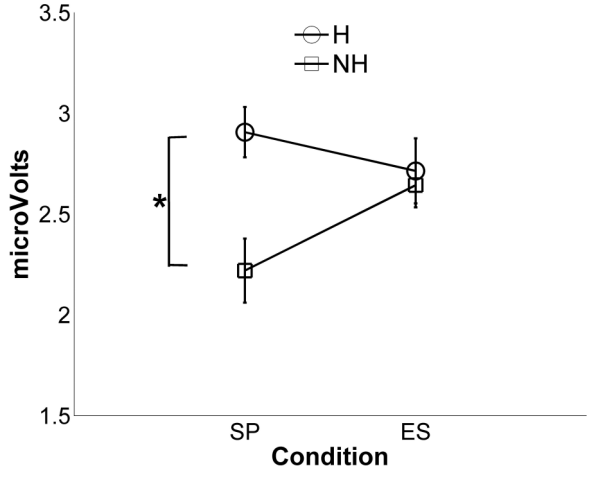

Figure 5. Mean amplitude of LPP (300–600 ms after SO) as a function of Condition by Stimulus. Error bars indicate *SEM*, adjusted for repeated-measures designs. The ANOVA revealed a significant Condition by Stimulus interaction. Post-hoc tests showed that the LPP was significantly larger for H than NH trials in the SP condition only.

($p < .01$) between H trials ($M = 2.9$, $SD = 1.84$) and NH trials ($M = 2.2$, $SD = 1.59$) in the SP condition. The predicted decrease of LPP amplitude for H trials in the ES condition ($M = 2.7$, $SD = 1.97$) did not reach significance ($p > .1$, *ns*). No other significant effects were found (all $p > .1$, *ns*).

DISCUSSION

The experiment presented here constitutes, to the best of our knowledge, the first investigation of the neural correlates of ES with ERPs. Participants watched and rated humorous or non-humorous pairs of pictures free of text and emotional faces either doing expressive suppression (ES) or—in a control condition—being free to respond spontaneously (SP) to the stimuli. Results show that, compared to neutral trials, trials that were rated as amusing elicited increased smiling, and a stronger LPP. ES was effective in reducing smiling, and eliminated the difference in LPP size between H and NH trials. However, ES did not modify feelings of amusement. In the following, we describe the results in more detail and discuss them in relation to the relevant literature.

Confirming our first hypothesis, participants successfully suppressed their facial reactions to H stimuli in the ES condition, as evident through reduced smiling rates and overall EMG activity, compared to the SP condition. Importantly, we were able to finely assess bilateral activity of the main smiling muscle, the zygomaticus major, using EMG, which provided an objective measure of the success of ES. Furthermore, the pictures used here did not show any emotional facial expressions, which might have triggered facial mimicry (Korb, Grandjean, & Scherer, 2010).

One of the goals of this experiment was to test whether subjective feelings of amusement diminish when participants suppress their facial reactions to amusing stimuli. Results showed that ES did not influence ratings of amusement, suggesting that it did not change participants' subjective feelings of emotion. This stands in contrast to earlier studies that found reduced feelings of amusement and/or positive emotions during ES (Gross & Levenson, 1997; Soussignan, 2002; Strack et al., 1988; Vrticka et al., 2011). However, others have not reported any ES-induced changes in subjective feelings of amusement (Zuckermann et al., 1981). Moreover, ES, despite reducing visible external signs of emotional arousal, typically does not affect subjective feelings of *negative* emotions (Gross, 1998a, 2002; Gross & Levenson, 1993, but see Goldin et al., 2008). As suggested by Duclos and Laird (2001), variability in participants' responsiveness to their physiological changes may prevent us from finding effects at the group level. Whether ES can lead to a reduction of positive (and sometimes even negative—see Goldin et al., 2008) subjective feelings remains – in light of the literature and of our results – controversial, and should be carefully addressed in future studies. In contrast, cognitive reappraisal has repeatedly been shown to reliably reduce not only the external but also the internal reactions to positive and negative emotional stimuli (Gross, 2002).

Trials rated as being H were accompanied by a greater LPP amplitude compared to NH trials, in the SP condition. This finding, which was expected, confirms previous reports of increased LPP amplitude to positive or negative emotional stimuli, compared to neutral ones (Olofsson et al., 2008; Schupp et al., 2000), and replicates the report of an increased LPP amplitude for H compared to NH visual stimuli by Gierych et al. (2005). Importantly, the LPP effect reported here cannot be attributed to a difference in the frequency of occurrence of H and NH trials, which was at the same rate (participants judged about half of the trials as being amusing). Nor can the LPP effect be due to eventual differences in low-level visual features of the stimuli, as (1) the LPP is knowingly quite insensitive to low-level perceptual characteristics of the stimuli (Bradley, Hamby, Löw, & Lang, 2007; Codispoti, Ferrari, & Bradley, 2007), and (2) across participants, the same pictures were seen in the SP and ES conditions, but a difference in LPP amplitude between H and NH stimuli was found only in the SP condition.

We had expected that ES would modify LPP size and thus change the way participants perceive H stimuli. This hypothesis was based on prior reports of reduced LPP amplitude through reappraisal (Hajcak & Nieuwenhuis, 2006; Krompinger et al., 2008; Moser et al., 2006, 2009), change of focus of attention (Dunning & Hajcak, 2009), distraction through thinking of something else (Thiruchselvam et al., 2011), or emotional versus unemotional judgments (Hajcak et al., 2006). In line with this, ES indeed changed participants' perception of H versus NH pictures, as shown by the Condition by Stimulus interaction resulting from the analysis of the LPP amplitudes. When participants focused on suppressing their facial reactions (ES condition), the LPP increase for H compared to NH stimuli observed in the SP condition disappeared. In other words, ES canceled the well-established and here replicated finding of increased LPP for emotional compared to neutral stimuli. This is, to the best of our knowledge, the first report of an LPP modulation through ES. Nevertheless, the hypothesis of a significant reduction of LPP amplitude

for H trials in the ES compared to the SP condition was not confirmed. A possible explanation for this null finding is the absence of changes in subjective feelings of amusement during ES. Indeed, in the context of the present experiment, we did not observe a direct link between LPP amplitude and the emergence of subjectively felt amusement.

The LPP component reported here has a posterior distribution with its maximum over electrode POz. In contrast, most previous studies found a more centroparietal topography with a maximum over CPz or Pz (Cacioppo, Whitfield, Gardner, & Berntson, 1994; Cuthbert et al., 2000; Hajcak & Nieuwenhuis, 2006; MacNamara & Hajcak, 2009; Sabatinelli, Lang, Keil, & Bradley, 2007; Schupp et al., 2000). However, other studies have also found posterior LPP effects in the past—for example, Dunning and Hajcak (2009) averaged the LPP over electrodes Pz, P1, P2, and POz. The literature's variations in the LPP's scalp distribution may relate to differences in the stimuli used. Indeed, the "late positivity to affective pictures is modulated both by their intrinsic motivational significance and the evaluative context of picture presentation" (Schupp et al., 2000, abstract). Finally, it is important to point out that many researchers did not record from more posterior electrodes than Pz, making a direct comparison with our data difficult.

Humor processing is thought to involve a stage in which an incongruity is detected, followed by the resolution of the incongruity and its ensuing emotional stage (e.g., Suls, 1972). The fact that the LPP amplitude is increased during emotional (Cacioppo et al., 1993; Cuthbert et al., 2000; Olofsson et al., 2008) and during humor processing (as shown by our results, as well as by Gierych et al., 2005) suggests that in the present experiment it reflects or at least partly contains the second stage of humor processing; that is, the amusement-inducing incongruity resolution. Another ERP component, the N400, might reflect more the detection of incongruity. Future ERP studies may attempt to disentangle incongruity detection from incongruity resolution, as Samson et al. (2008) did in a recent fMRI study.

The earliest effect of ES on the ERP was in the LPP window. Two early components (peaking at 27 and 62.5 ms over posterior electrodes)—possibly generated by the succession of two highly similar pictures without any intervening blank screen—and the P1 (peaking at 105 ms) were modulated neither by the effect of the Stimulus (H vs. NH) nor by the effect of the Condition (ES vs. SP). In contrast, Gierych et al. (2005) found increased positive potentials for H versus NH pictures from 200 ms onward. These differences in latency may derive from the fact that we used rather complex images, often depicting several objects or entire scenes, which may have somewhat delayed and/or prolonged humor processing. In comparison, Gierych and colleagues used simple drawings or pictures of single household objects. Future studies could therefore assess the speed of humor processing, using visual stimuli of different complexities.

Several previous studies investigating emotion regulation with ERPs have also found significant modulations of the electrophysiological components through cognitive reappraisal from approximately 300 ms onward (e.g., Krompinger et al., 2008). However, there have also been reports of effects of reappraisal from 200 ms (Hajcak & Nieuwenhuis, 2006) or 250 ms (Moser et al., 2006) onward. The fact that several studies reported earlier effects of reappraisal than the latency reported here for the suppression effect is in line with the emotion-regulation sequence postulated by Gross. In fact, Gross' theory (Gross, 1998b; Gross & Thompson, 2007) predicts that reappraisal—a so-called antecedent-focused regulation strategy—sets in earlier in the unfolding of the emotional response than ES—a response-focused regulation strategy. Also in agreement with this proposition, a recent fMRI study (Goldin et al., 2008) reported earlier PFC activation for reappraisal than for ES. However, latencies reported in this study were in the seconds range, and may not be directly comparable to ERP data. It is possible (although unlikely, as participants' stimulus appreciation and response times did not change across conditions) that the block design used here, in which participants may have prepared to suppress their emotional expressions even before the stimuli were presented, led to earlier effects of ES on the LPP. We chose this design in order to reduce task-switching demands (for a discussion of the advantages of block designs in emotion regulation experiments, see Moser et al., 2009; Thiruchselvam et al., 2001). Future studies could, however, investigate the assumed difference in timing between reappraisal and ES by using an event-related design, in which instructions to apply either one or the other form of emotion regulation follow (instead of preceding) stimulus onset (e.g., Hajcak, Dunning, & Foti, 2009).

This study suffers from certain limitations. First, the stimuli used were well suited for EEG studies, but were less amusing than humorous films. As a result, true smiles were quite rare, and the difficulty of the ES task may have been low. Possibly, using more amusing stimuli may lead to greater LPP amplitude and more frequent smiling in the SP condition, and/or to a greater reduction of the LPP amplitude during ES—a question future studies may want to address. Nevertheless, some of our participants reported having

difficulty in suppressing their smiling reaction to the H trials.

A potential limitation of the study is that it did not control for the impact of increased cognitive demands during emotion regulation compared to the control condition. Indeed, some studies have reported reduced LPP amplitude in response to emotional stimuli with increasing cognitive load (MacNamara et al., 2011; for a review, see also Schupp et al., 2006). However, others have claimed that "the affective modulation of neural activity during picture viewing is relatively automatic and is insusceptible to competing task demands" (Hajcak et al., 2007, abstract). Also in line with this latter proposition, reappraisal (which most likely involves an additional cognitive load compared to stimulus watching alone) has been shown (according to the instructions) to both decrease and increase the amplitude of the LPP triggered by emotional scenes (Moser et al., 2009). Thus, the effects of cognitive load, caused by a secondary task, upon LPP amplitude in response to affective pictures remain unclear. In relation to our experiment, it is likely that the ES condition involved a greater cognitive load than the SP condition. However, cognitive load alone would have resulted in a general decrease of LPP size for both H and NH trials (MacNamara et al., 2011), which we did not observe. Thus, the results speak in favor of the hypothesis that the observed changes in LPP amplitude have been specifically generated by ES, and not by cognitive load alone. Future studies should, however, add a further cognitively demanding condition—for example, one in which participants exaggerate their emotional facial expressions (Demaree, Robinson, et al., 2004; Demaree, Schmeichel, Robinson, & Everhart, 2004), or should attempt to distinguish between cognitive loads that are specific and unspecific to emotion-regulation processes. An exaggeration condition is, however, likely to lead to substantial movement and muscular artifacts in the EEG data, complicating its analyses (in relation to that, Giuliani et al., 2008, found that increasing amusement through reappraisal leads to greater smiling and laughing).

A potential disadvantage of our design is that the ES blocks contained NH in addition to H stimuli, and this may have confused participants. This design was chosen to prevent habituation to H stimuli, but it cannot be excluded that it impacted the way NH stimuli were processed in the ES condition. Therefore, the question remains open whether ES in a block design comprising only H pictures would lead to different results.

It would have been interesting to verify by eye-tracking measures that participants did not attend to less arousing parts of the pictures during the ES condition, a behavior that can occur during reappraisal (van Reekum et al., 2007), and that can decrease the LPP to emotional stimuli (Dunning & Hajcak, 2009; MacNamara & Hajcak, 2009 – but see Bebko, Franconeri, Ochsner, & Chiao, 2011, suggesting that more successful regulators actually spend more time looking at emotional parts of negative scenes). However, the fact that the number of trials subjectively rated as being H did not differ between conditions makes this hypothesis less likely. Moreover, a recent study by Urry (2010) suggests that reappraisal can modulate ratings of emotional intensity, corrugator activity, and autonomic arousal, even when participants' gaze is held constant. Finally, the inclusion of additional physiological measures, such as heart rate, respiration, and skin conductance, would have been helpful to assess participants' effort during the ES condition.

In summary, H visual stimuli, free of text and emotional facial expressions, were rated as being more amusing, generated more smiling, and led to an increased LPP compared to NH stimuli. Participants' suppression of facial expressions in response to H stimuli reduced smiling, abolished the LPP effect for H stimuli, but did not affect feelings of amusement. Our results confirm previous findings of increased LPP for H versus NH visual stimuli (Gierych et al., 2005), and show for the first time a modulation of the LPP through ES. Based on these findings, H visual stimuli elicit emotional arousal in a way that is comparable to the arousal caused by classically used positive and negative emotional scenes, such as the IAPS (Lang et al., 1999). Differences in the cognitive processes and the neural activity involved in the perception of H and NH emotional stimuli, as well as in the regulation of emotional reactions, are nevertheless likely to exist, and should be directly compared in future studies. In addition, future studies could include a greater number of emotion-regulation conditions (e.g., exaggeration) and also test the effects of ES on the LPP during the perception of stimuli of different type and valence.

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