Social Cognitive and Affective Neuroscience Advance Access published September 30, 2016

OXFORD

Social Cognitive and Affective Neuroscience, 2016, 1–9

doi: 10.1093/scan/nsw114
Original article

Neural processing of emotional-intensity predicts emotion regulation choice

Roni Shafir,[1] Ravi Thiruchselvam,[2,*] Gaurav Suri,[3,*] James J. Gross,[3] and Gal Sheppes[1]

[1]The School of Psychological Sciences, and Sagol School of Neuroscience, Tel Aviv University, Tel Aviv, Israel, [2]Department of Psychology, Hamilton College, Clinton, NY, USA, and [3]Department of Psychology, Stanford University, Stanford, CA, USA

*R. Thiruchselvam and G. Suri contributed equally to this work.
Correspondence should be addressed to Roni Shafir, Gal Sheppes, The School of Psychological Sciences, Tel Aviv University, Tel Aviv 69978, Israel.
E-mail: ronishafir@mail.tau.ac.il., sheppes@post.tau.ac.il.

Abstract

Emotional-intensity is a core characteristic of affective events that strongly determines how individuals choose to regulate their emotions. Our conceptual framework suggests that in high emotional-intensity situations, individuals prefer to disengage attention using distraction, which can more effectively block highly potent emotional information, as compared with engagement reappraisal, which is preferred in low emotional-intensity. However, existing supporting evidence remains indirect because prior intensity categorization of emotional stimuli was based on subjective measures that are potentially biased and only represent the endpoint of emotional-intensity processing. Accordingly, this study provides the first direct evidence for the role of online emotional-intensity processing in predicting behavioral regulatory-choices. Utilizing the high temporal resolution of event-related potentials, we evaluated online neural processing of stimuli's emotional-intensity (late positive potential, LPP) prior to regulatory-choices between distraction and reappraisal. Results showed that enhanced neural processing of intensity (enhanced LPP amplitudes) uniquely predicted (above subjective measures of intensity) increased tendency to subsequently choose distraction over reappraisal. Additionally, regulatory-choices led to adaptive consequences, demonstrated in finding that actual implementation of distraction relative to reappraisal-choice resulted in stronger attenuation of LPPs and self-reported arousal.

Key words: emotion regulation choice; distraction; reappraisal; emotional-intensity; late positive potential

Introduction

Individuals have an impressive ability to actively modify their emotions using various regulatory strategies. In recent years it has become clear that while a certain strategy may prove adaptive in a particular emotional situation, it may lead to maladaptive outcomes in another. Therefore, the ability to adequately choose between various regulatory strategies in accordance with differing situational demands is considered to be crucial for healthy adaptation (see Webb *et al.*, 2012; Bonanno and Burton, 2013; Sheppes and Levin, 2013; Aldao and Tull, 2015; Gross, 2015; Sheppes *et al.*, 2015 for conceptual reviews).

Despite its conceptual importance, empirical examination of regulatory-choices has only recently become a focus of interest in the field of emotion regulation (Bonanno *et al.*, 2004; Sheppes *et al.*, 2011, 2014a; Aldao and Nolen-Hoeksema, 2013). In several studies, a special focus was devoted to examine how the evaluation of central characteristics of emotional situations leads individuals to favor one regulatory strategy over

Received: 26 October 2015; **Revised:** 5 August 2016; **Accepted:** 9 August 2016

the other. For example, the evaluation of how aversive a dental procedure is likely to be can influence the regulatory-choice between thinking about unrelated errands during the dental procedure *vs* contemplating the long-term benefits of healthy teeth.

Our recently developed framework (Sheppes and Levin, 2013) demonstrates how the evaluation of one central characteristic of emotional situations, namely their intensity level, influences the choice between central regulatory strategies (Reisenzein, 1994. See Dixon-Gordon *et al.*, 2015 for a review). Emotional-intensity determines the degree of activation in response systems that form emotional responses (Bradley *et al.*, 2001). The regulatory strategies in our conceptual framework differ in one central dimension, namely whether strategies generally involve disengaging via diverting cognition away from emotional situations, or engaging via sustained attention to, or work on, emotional responses (Parkinson and Totterdell, 1999). Specifically, one central disengagement regulatory strategy is distraction, that involves disengaging from emotional contents by producing unrelated neutral thoughts at an early attentional deployment stage (Van Dillen and Koole, 2007). One central engagement regulatory strategy is reappraisal, that involves attentional engagement with emotional information prior to reinterpreting its initial meaning at a late semantic meaning stage (Gross, 1998; Sheppes and Gross, 2011).

According to our conceptual framework (Sheppes and Levin, 2013), varying intensity levels of emotional events lead individuals to differentially choose between disengagement distraction and engagement reappraisal. Particularly, disengagement distraction is more likely to be chosen over reappraisal in high emotional-intensity situations, because distraction can more effectively block potent emotional information early before it gathers force (Sheppes and Meiran, 2007; Sheppes and Gross, 2011; Sheppes *et al* 2014b; Shafir *et al.*, 2015). In contrast, engagement reappraisal is more likely to be chosen over distraction in low emotional-intensity situations, because reappraisal effectively modulates mild emotional reactions, while also altering how emotional events are perceived (Wilson and Gilbert, 2008; Macnamara *et al.*, 2011; Thiruchselvam *et al.*, 2011; Blechert *et al.*, 2012; Denny *et al.*, 2015).

Strong empirical evidence for these regulatory-choices was demonstrated in many behavioral studies (e.g. Sheppes *et al.*, 2011, 2014a; Hay *et al.*, 2015; Levy-Gigi *et al.*, 2015; Scheibe *et al.*, 2015). In a typical study, emotional pictures that vary in their subjective emotional-intensity level (high *vs* low) are presented in different trials. Each picture is followed by participants' choice of whether they prefer to regulate their emotions via disengagement distraction or engagement reappraisal.

Although these prior behavioral studies provide significant evidence regarding the role of emotional-intensity level in predicting which of the two regulatory strategies is more likely to be chosen, this evidence is indirect. Particularly, in all of these studies the intensity level categorization of pictorial emotional stimuli was based on subjective ratings of intensity [International Affective Picture System (IAPS) normative ratings: Lang *et al.*, 2008]. Although important, subjective ratings suffer from several shortcomings. First, subjective ratings are prone to multiple reporting biases. In our case, self-reports of emotional-intensity may derive from tacit knowledge regarding how one should feel, rather than how one actually feels, in response to emotional pictures (e.g. Nisbett and Wilson, 1997; Rosenthal and Rosnow, 2009). Most importantly, self-report measures at best only represent the endpoint or outcome of intensity information processing, rather than actual underlying online processing of intensity information.

Therefore, this study was set to provide the first direct evidence of individuals' online processing of stimuli's emotional-intensity in emotion regulation choice. Furthermore, examining online processing of emotional-intensity would prove particularly useful if it could improve the prediction of subsequent regulatory-choices, beyond subjective ratings.

In recent years, it has become apparent that neural measures can be utilized to elucidate underlying processing of central attributes of stimuli, that can predict various choice behaviors (see Fellows, 2004; Rangel *et al.*, 2008; Kable and Glimcher, 2009; Levy and Glimcher, 2012 for conceptual reviews). For example, recent studies in neuro-economics applied underlying neural processing of products' value to predict products' chances to be subsequently chosen (e.g. Ravaja *et al.*, 2013; Telpaz *et al.*, 2015. See Fehr and Rangel, 2011; Padoa-Schioppa, 2011 for conceptual reviews).

Drawing from this line of research, in this study we examined the role of online neural processing of emotional-intensity in predicting behavioral choices between disengagement distraction and engagement reappraisal. To that end, we employed event-related potentials (ERPs), which are temporally sensitive enough to detect rapidly evolving emotional-intensity processing (Luck, 2014). Specifically, we focused on the late positive potential (LPP), perhaps the most well-known ERP component for measuring online processing of emotional information that varies in intensity (see Hajcak *et al.*, 2010 for a review). The LPP is a centro-parietal positive-going wave that becomes evident ~300 ms following stimulus onset, showing enhanced amplitudes as the processing of emotional-intensity increases (Hajcak *et al.*, 2009).

Consistent with our conceptual framework and previous behavioral findings, we expected that subjective intensity level of emotional pictures (high *vs* low) would strongly predict regulatory-choices. Specifically, low-intensity stimuli would lead to reappraisal preference whereas high-intensity stimuli would lead to distraction preference. Extending prior behavioral findings and consistent with our framework, we expected that the neural intensity processing of emotional pictures (henceforth pre-choice-LPP) would improve the prediction of subsequent regulatory-choices. Particularly, an increase in pre-choice-LPP amplitudes would be uniquely associated with higher chances of subsequently choosing distraction over reappraisal.

A secondary goal of this study was to explore the consequences of actually executing or implementing regulatory-choices. To that end, we examined neural intensity processing during actual implementation of regulatory-choices (henceforth implementation-LPP), as well as self-reported arousal and unpleasantness ratings immediately following regulatory implementation. Since the LPP reflects the degree of emotional-intensity processing, its attenuation during regulatory implementation denotes regulatory success (Hajcak and Nieuwenhuis, 2006; Moser *et al.*, 2006; Dennis and Hajcak, 2009). Congruent with previous studies showing stronger LPP attenuation during distraction, as compared with reappraisal implementation (Thiruchselvam *et al.*, 2011; Paul *et al.*, 2013; Schönfelder *et al.*, 2014), we hypothesized that distraction relative to reappraisal-choices' implementation would result in enhanced attenuation of implementation-LPPs.

Correspondingly, Previous behavioral findings showed enhanced attenuation of self-reported emotional-intensity following distraction, as compared with reappraisal implementation (Sheppes and Meiran, 2007; Sheppes et al., 2014b). Accordingly, we predicted that distraction relative to reappraisal-choices' implementation would result in enhanced attenuation of self-reported arousal and unpleasantness.

Methods

Participants

Twenty-five students participated in the experiment.[1] One participant who did not complete the experiment was excluded from analyses. Therefore, the final sample consisted of 24 participants (mean age 20.17 years, 14 men).

Stimuli

144 negative pictures were chosen from previously validated pictorial datasets[2] (IAPS; Lang et al., 2008). High-intensity pictures ($n = 72$, $M_{\text{arousal}} = 6.44$, $M_{\text{valence}} = 2.01$) differed significantly from low-intensity pictures ($n = 72$, $M_{\text{arousal}} = 5.65$, $M_{\text{valence}} = 2.85$) in both valence and arousal subjective normative ratings (both Fs > 42.2, Ps < 0.001, $\eta_p{}^2$s > 0.37, c.f. Sheppes et al., 2011, 2014a). Emotional pictures included various negative contents such as sadness, threat and fear, and were matched across the two intensity categories when possible.

Procedure

Participants performed an emotion regulation choice task (Sheppes et al., 2011; Sheppes et al., 2014a; Levy-Gigi et al., 2015; Shafir et al., 2015) while continuous Electroencephalography (EEG) was recorded. First, participants learned how to implement distraction and reappraisal (order of learning counterbalanced across participants). During this phase, the experimenter made sure that participants understood the regulation strategies properly by asking them to talk out loud how they implement each strategy. If needed, participants were corrected by the experimenter. Participants then underwent an eight trial practice phase (four trials for each intensity category), in which they practiced choosing between distraction and reappraisal.

Distraction instructions involved forming emotionally neutral thoughts that are unrelated to the emotional picture (i.e. thinking about familiar streets or about performing daily activities), thus disengaging attention from emotional contents. Reappraisal instructions involved engaging with the emotional picture but reinterpreting its emotional meaning (i.e. thinking that the situation would improve or considering less negative elements of the emotional situation). We did not allow participants to form reality challenge reappraisals (e.g. thinking of the situation as unreal), because these reappraisals function as a form of disengagement (see Sheppes et al., 2014a, Study 6 for details).

The task consisted of 144 trials (divided to 6 equally long blocks, separated by short breaks). Pictures of low and high emotional-intensity were presented randomly, with the restriction that no more than two trials of the same emotional-intensity category repeat in sequence.

Each trial (see Figure 1) began with a 1500 ms fixation cross, followed by a 1000 ms initial preview of the emotional picture (henceforth pre-choice window), followed by a 1500 ms fixation cross. Then a 3000 ms Choice screen was presented, during which participants were asked to consider whether they prefer to regulate their emotions via distraction or reappraisal. Participants were instructed to choose the regulatory option which they assume would be more efficient in reducing their negative emotions in reaction to each emotional picture. Another screen was then presented and participants were asked to indicate their chosen strategy by pressing a left or right button (assignment of button to strategy was counterbalanced across trials). Following a 1500 ms fixation cross, the same picture was presented again for 5000 ms, during which participants implemented their chosen strategy (henceforth implementation window). The offset of each picture was followed by two 1–9 rating scales in which participants reported their experienced valence (1 = pleasant, 9 = unpleasant) and arousal (1 = calm, 9 = excited) using the Self-assessment Manikin (SAM, Lang et al., 2008).

Electrophysiological recordings, data reduction and analysis

Scalp EEG was recorded using the Neuroscan recording system (Neuroscan, Inc., Herndon, VA, USA) from 19 electrode sites (Fz, FCz, Cz, CPz, POz, Pz, Oz, FP1/2, F3/4, C3/4, CP1/2, P3/4, O1/2), as well as two additional electrodes placed on the left and right mastoids. During recording, Pz electrode served as the online reference. The vertical electrooculogram was recorded from two electrodes placed ~1 cm beneath and above the left eye. EEG data was sampled at 1000 Hz.

Offline signal processing was carried out using EEGLAB and the ERPLAB Toolbox (Delorme and Makeig, 2004; Lopez-Calderon and Luck, 2014). Data from all electrodes were re-referenced to the average activity of the left and right mastoids. Continuous EEG data was band-pass filtered (cutoffs: 0.05–20Hz; 12 dB/oct rolloff). Eye-movement artifacts were removed using an Independent Component Analysis (ICA) approach (Delorme and Makeig, 2004; Mennes et al., 2010).

For the pre-choice-LPP analysis, the EEG was epoched into 1200 ms segments, starting 200 ms (baseline) before the onset of the pre-choice window and lasting 1000 ms (end of the pre-choice window). Similarly, for the implementation-LPP analysis, the EEG was epoched into 5200 ms segments, starting 200 ms (baseline) before the onset of the implementation window and lasting 5000 ms (end of the implementation window). All trials exceeding 80 μV within 200 ms were rejected. The mean rejection rate was 0.75%, SE = 0.01 for the pre-choice window analysis and 0.76%, SE = 0.01 for the implementation window analysis, and did not vary between conditions [both Fs < 1.69, n.s.].

The pre-choice-LPP was defined as the mean amplitude between 300 (when it becomes evident, see Hajcak et al., 2010) and 1000 ms (end of the pre-choice window). The implementation-LPP analysis was defined as the mean amplitude between 300 and 5000 ms (end of the implementation window). The LPP was measured as the average activity over centro-parietal electrode sites, where it is maximal (CPz, CP1 and CP2, e.g. Thiruchselvam et al., 2011).

Results

Does neural processing of emotional-intensity improve regulatory-choice prediction?

Based on our conceptual framework and prior findings, we expected that for the high relative to the low subjective emotional-intensity category participants would be more likely to choose distraction over reappraisal. Importantly, we hypothesized that beyond the predictive value of subjective emotional-intensity categorization for regulatory-choices,

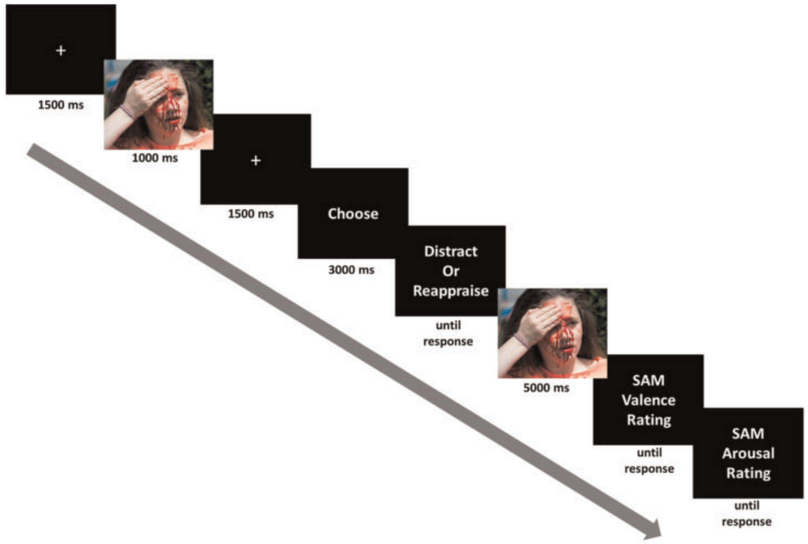

Fig. 1. Trial structure of the emotion regulation choice task. SAM stands for Self-assessment Manikin.

increased pre-choice-LPPs would be associated with higher odds of subsequently choosing distraction over reappraisal.

To test these two hypotheses, we applied a Logistic Mixed Effects Model (using the PROC GLIMMIX procedure in SAS 9.3; SAS Institute, Cary, NC, USA). Binary regulatory-choices of all participants in all trials, either to distract (receiving the value 1) or to reappraise (receiving the value 0), were entered as a criterion variable, with single-trial subjective emotional-intensity category (high or low, based on IAPS norms) and single-trial (continuous) pre-choice-LPPs as predictors. In order to minimize type I error (see recommendations by Barr *et al.*, 2013), random slopes were defined for the two predictors (see also Supplementary Table S1 showing higher fit for this model relative to alternative models). Since LPP amplitudes differ between low and high emotional intensities, for each subject separately every single-trial pre-choice-LPP value of a picture of a certain intensity category (either high or low) was centered relative to the average pre-choice-LPP amplitude of the same intensity category.[3] This procedure enabled us to compare between pre-choice-LPPs of different intensity categories.

Confirming our hypothesis, we found a main effect of subjective emotional-intensity category [$b = 1.9$, $F(1,23) = 113.43$, $P < 0.001$], with 6.68 increase of the odds for choosing distraction following high *vs* low-intensity stimuli [OR = 6.68, $P < 0.001$, 95% CI: (4.63, 9.71)]. Importantly, confirming our second hypothesis we also found a main effect of pre-choice-LPP amplitudes [$b = 0.02$, $F(1,23) = 17.78$, $P < 0.001$], such that 1 microvolt (μV) increase in pre-choice-LPP amplitudes was uniquely related to 2% increase of the odds for subsequently choosing distraction over reappraisal [OR = 1.02, $P < 0.001$, 95% CI: (1.009, 1.028)][4] (see Figure 2). Given the relatively large μV range of single-trial pre-choice-LPPs, there is a considerable accumulative increase of the odds for choosing distraction over reappraisal as pre-choice-LPP amplitudes increase. Note that we did not expect nor did we find an interaction between the two predictors [$F = 0.04$, 95% CI: (−0.02, 0.02)].

In addition to conventional null hypothesis significance testing, which suffers from several flaws (Cumming, 2013), we estimated the observed effects using likelihood intervals (LIs).[5] LIs consist of a set of possible values for the parameter of interest that are consistent with the observed data. For example, the LI of the pre-choice-LPP predictor consists of Beta values (i.e. values which define the relationship between pre-choice-LPPs and regulatory-choices) supported by the data. Values within the 1/8 LI (corresponding to a 95.9% CI) are consistent with the data, as they are no <1/8 as likely as the maximum-likelihood estimate (i.e. the observed Beta) (Van der Tweel, 2005; Dienes, 2008). Since the log of the regression slope in logistic regressions is approximately normally distributed, we used a LI calculation for a mean of normal distribution with unknown variance (Dienes, 2008). Observed LIs for the pre-choice-LPP: 1/8 LI [0.009, 0.028], for emotional-intensity category: 1/8 LI [1.51, 2.28], for the non-significant interaction between the two predictors: 1/8 LI [−0.02, 0.02]).

Additional analyses were performed in order to mitigate concerns related to the neural pre-choice-LPP measure. First, since pre-choice-LPPs vary considerably across trials and subjects, we confirmed in complementary analyses that the observed pre-choice-LPP findings are not driven by outliers at the trial (see Supplementary Figure S6) or subject (see Supplementary Figure S7) level. Second, we wished to mitigate the concern that our continuous pre-choice-LPP measure has predictive value simply because it is more sensitive than the dichotomous subjective emotional-intensity category measure. Specifically, we ran two Logistic Mixed Effects Models where we replaced the dichotomous subjective emotional-intensity measure with *continuous* arousal (first analysis) and valence[6] (second analysis) emotional-intensity measures (i.e. the two continuous subjective measures that define the low and high emotional-intensity categories). Congruent with findings obtained with the dichotomous subjective emotional-intensity measure, we found a main effect of continuous arousal [$b = 0.76$, 1/8 LI (0.64, 0.87), $F(1,23) = 210.59$, $P < 0.001$, OR = 2.13, $P < 0.001$, 95% CI: (1.91, 2.37)] and valence [$b = 1.36$, 1/8 LI (1.11, 1.62), $F(1,23) = 138.04$, $P < 0.001$, OR = 3.91, $P < 0.001$, 95% CI: (3.07, 4.97)]. Importantly, in these models the pre-choice-LPP remained a meaningful predictor [$b = 0.01$, 1/8 LI (0.004, 0.02), $F(1,23) = 10.89$, $P = 0.003$, OR = 1.01, $P < 0.001$, 95% CI: (1.005, 1.02)] in the model including continuous arousal; $b = 0.01$, 1/8 LI [0.005, 0.02], $F(1,23) = 10.72$, $P = 0.003$, OR = 1.01, $P < 0.001$, 95% CI: (1.005, 1.02) in the model including continuous valence]. Note that in an additional analysis that included pre-choice-LPPs as well as *both* continuous arousal and valence as

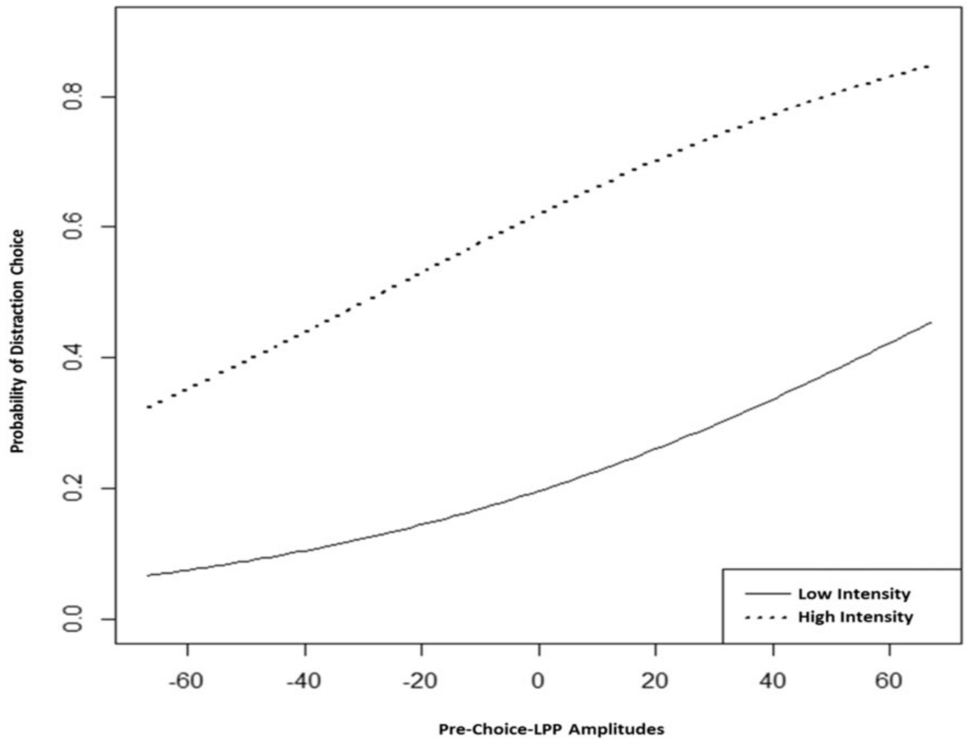

Fig. 2. Prediction of regulatory-choices based on subjective emotional-intensity categories and pre-choice-LPPs. Probability of choosing to regulate via distraction (y-axis) as a function of μV increase in pre-choice-LPP amplitudes (x-axis), in low (continuous line) and high (dotted line) subjective emotional-intensity categories. Density of the pre-choice-LPPs and data from individual subjects are included in Supplementary materials (Supplementary Figures S4 and S5, respectively). Note that for this Figure we used raw (non-centered) pre-choice-LPP amplitudes.

regulatory-choice predictors, pre-choice-LPP remained a meaningful predictor [$b = 0.01$, 1/8 LI (0.004, 0.02), $F(1,23) = 9.9$, $P = 0.005$, OR = 1.01, $P < 0.005$, 95% CI: (1.004, 1.022)].

Do regulatory-choices have adaptive consequences?

Attenuation of neural processing during implementation. In this analysis we tested whether distraction relative to reappraisal-choices' implementation resulted in enhanced attenuation of implementation-LPPs. To equate initial pre-choice-LPP differences between distraction-chosen and reappraisal-chosen trials, for each condition the mean pre-choice-LPP amplitude served as a pre-regulation baseline (see Figure 3A) from which we subtracted the mean implementation-LPP amplitude (see Figure 3B).[7] Thus, the outcome variable was computed as (mean pre-choice-LPP)—(mean implementation-LPP), with higher scores indicating stronger attenuation of implementation-LPPs (i.e. stronger regulatory success). We then employed a 2 × 2 analysis of variance (ANOVA) with Emotional-Intensity Category (low, high) and Regulatory-Choice (distraction, reappraisal) as repeated measures factors.[8] Confirming our hypothesis, we found a Regulatory-Choice main effect [$F(1,22) = 16.96$, $P < 0.001$, $\eta_p^2 = 0.44$, 1/8 LI (1.29, 4.18)], with higher attenuation of implementation-LPP amplitudes during distraction ($M = 3.97$, $SE = 1.11$), as compared with reappraisal ($M = 1.23$, $SE = 1.25$) implementation. Note that we did not expect nor did we find an Emotional-Intensity Category × Regulatory-Choice interaction [$F = 0.003$, 95% CI: (−5.3, 5.05), 1/8 LI (−5.51, 5.33)]. Additionally, this analysis revealed an Emotional-Intensity Category main effect [$F(1,22) = 6.66$, $P = 0.017$, $\eta_p^2 = 0.23$, 1/8 LI (0.33, 3.95)], with higher attenuation of implementation-LPP amplitudes in high ($M = 3.67$, $SE = 1.25$) relative to low ($M = 1.53$, $SE = 1.16$) intensity, suggesting that regulatory implementation was in general more efficient when facing high, as compared with low-intensity stimuli.

Attenuation of self-reported post-regulatory implementation ratings. In these analyses, we tested whether distraction relative to reappraisal-choices' implementation resulted in enhanced attenuation of self-reported arousal and unpleasantness. Similar to the implementation-LPP analysis, the outcome variable was computed as (mean IAPS normative pre-regulation arousal/valence[6] ratings) − (mean Subject's self-reported post-regulation arousal/valence ratings),[7] with higher scores indicating stronger reduction in arousal/unpleasantness (i.e. stronger regulatory success). We then employed two 2 × 2 ANOVAs for arousal and valence ratings separately, with Emotional-Intensity Category (low, high) and Regulatory-Choice (distraction, reappraisal) as repeated measures factors.[8]

Self-reported arousal analysis. Confirming our hypothesis that distraction relative to reappraisal-choice implementation would result in reduced self-reported arousal levels, we found a Regulatory-Choice main effect [$F(1,22) = 28.72$, $P < 0.001$, $\eta_p^2 = 0.57$, 1/8 LI (0.6, 1.43)], with higher attenuation of self-reported arousal post-distraction ($M = 0.72$, $SE = 0.25$), as compared with reappraisal ($M = -0.29$, $SE = 0.26$) implementation. We did not expect nor did we find an Emotional-Intensity Category × Regulatory-Choice interaction [$F = 0.31$, 95% CI: (−1.2, 1.1), 1/8 LI (−1.22, 1.18)]. Additionally, this analysis revealed an Emotional-Intensity Category main effect [$F(1,22) = 104.98$, $P < 0.001$, $\eta_p^2 = 0.83$, 1/8 LI (1.1, 1.7)], with higher reduction in self-reported arousal post-regulation of high ($M = 0.92$, $SE = 0.23$) relative to low ($M = -0.48$, $SE = 0.26$) intensity stimuli, suggesting that regulatory

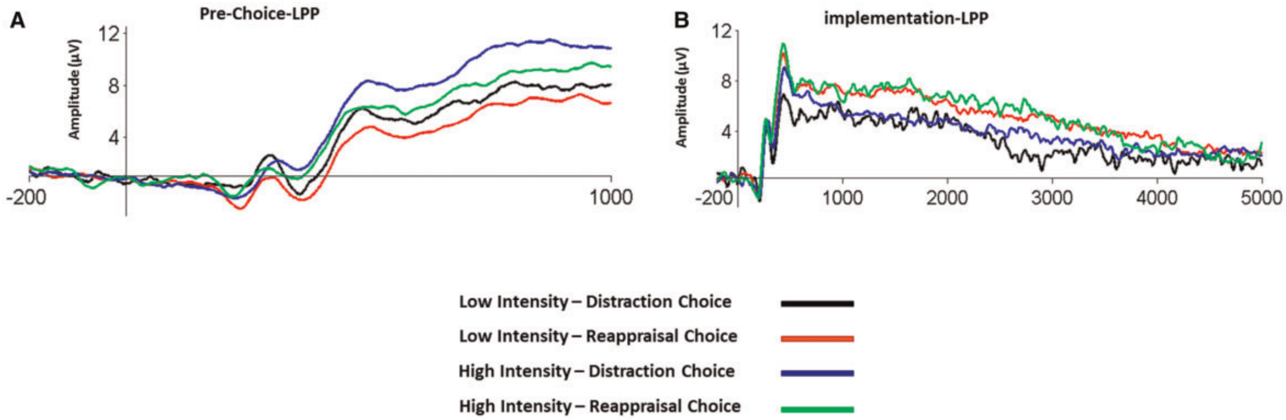

Fig. 3. Neural consequences of regulatory-choices. Pre-choice-LPP amplitudes **(A)** and implementation-LPP amplitudes (that do not involve subtraction from mean pre-choice-LPP amplitudes) **(B)** for distraction and reappraisal-choice in low and high subjective emotional-intensity categories. Waveforms are averaged across CPz, CP1 and CP2 electrodes. The x-axis runs from the beginning of the baseline (−200 ms pre picture onset) to the end of the picture's presentation—1000 ms for the pre-choice window (A) and 5000 ms for the implementation window (B).

implementation was generally more efficient in reducing arousal levels of high, as compared with low-intensity stimuli.

Self-reported valence analysis. Somewhat unexpectedly the direction of the Regulatory-Choice main effect [$F(1,22) = 18.09$, $P < 0.001$, $\eta_p^2 = 0.45$, 1/8 LI (0.32, 1)] indicated that reappraisal implementation was associated with higher reduction in self-reported unpleasantness ($M = 2.32$, $SE = 0.2$), as compared with distraction ($M = 1.67$, $SE = 0.18$) implementation. We did not expect nor did we find an Emotional-Intensity Category × Regulatory-Choice interaction [$F = 0.66$, 95% CI: (−0.9, 0.8), 1/8 LI (−0.9 0.82)]. Additionally, this analysis revealed an Emotional-Intensity Category main effect [$F(1,22) = 5.46$, $P = 0.029$, $\eta_p^2 = 0.2$, 1/8 LI (0.02, 0.54)], with higher reduction in self-reported unpleasantness post-low ($M = 2.13$, $SE = 0.17$) relative to high ($M = 1.86$, $SE = 0.2$) intensity, suggesting that regulatory implementation was generally more efficient in reducing self-reported unpleasantness of low relative to high emotional-intensity stimuli.

Discussion

Although emotional-intensity is considered a central characteristic of emotional events that strongly influences subsequent regulatory-choices, little is known about the online processing of emotional-intensity that leads to choice. This study demonstrates for the first time that direct neural processing of stimuli's emotional-intensity uniquely predicts behavioral regulatory-choices between disengagement distraction and engagement reappraisal.

Consistent with our conceptual framework and previous behavioral findings (Sheppes *et al.*, 2011, 2014a; Hay *et al.*, 2015; Levy-Gigi *et al.*, 2015; Scheibe *et al.*, 2015), we found that subjective intensity level of emotional pictures (high *vs* low) strongly predicted regulatory-choices. Specifically, in high relative to low subjective emotional-intensity, disengagement distraction, which can more effectively block highly potent emotional information early before it gathers force (Sheppes and Gross, 2011), was more likely to be chosen, as compared with engagement reappraisal. Extending these prior behavioral findings and consistent with our framework, we showed that the neural intensity processing of emotional pictures improved the prediction of regulatory-choices. Specifically, increased pre-choice-LPP amplitudes were uniquely associated with higher odds for subsequent distraction choice.

Additionally, in this study we tested the consequences of implementing regulatory-choices. We predicted and found that distraction relative to reappraisal-choice implementation resulted in stronger attenuation of implementation-LPPs as well as self-reported arousal (but not unpleasantness).

The present results enrich our original conceptual framework (Sheppes and Levin, 2013) by directly elucidating the role of emotional-intensity in determining regulatory-choices. In our original conceptual framework, the intensity level predictor of regulatory-choices was based on subjective intensity categorization of emotional stimuli. Although important, subjective intensity only represents the end point of intensity information processing. Therefore, this study provides the first evidence for the role of direct neural intensity processing in predicting regulatory-choices. Moreover, finding similar directionality in the neural and subjective measures strengthens the conceptual relationship between enhanced intensity (either neural or subjective) and distraction over reappraisal preference.

Relative to the strong effect of subjective emotional-intensity category on regulatory-choices, the neural pre-choice-LPP measure was modest in its contribution. However, we wish to make several empirical and conceptual arguments that together increase our confidence in the validity of our neural predictor. Empirically, we were able to show that the unique predictive value of pre-choice-LPPs could not be attributed to the influence of trial or subject level outliers, or to the continuous nature of the pre-choice-LPP measure. In addition, despite the relatively small odds ratio value, the relatively large µV range of single-trial pre-choice-LPPs allows a considerable accumulative increase of the odds for choosing distraction over reappraisal as pre-choice-LPP amplitudes increase. Furthermore, converging support for the validity of our neural measure was obtained with analyses that overcome limitations associated with null hypothesis significance testing. Conceptually, the pre-choice-LPP represents a direct online neural measure of emotional-intensity processing. As such, the pre-choice-LPP may hint at distal causal relationships that are crucial for detecting the actual mechanism by which intensity processing influences regulatory-choices (Lance and Vandenberg, 2009).

This study extends the important contribution of neural measures in understanding various classic choice behaviors, to a relatively new choice domain that concerns behavioral choices in emotion regulation. Although it shares a common logic with other choice domains, the study of emotion regulation choice is also unique. Neural processing of information in other choice domains usually predicts external behavioral preferences, such as whether or not to buy a product, which career path to pursue etc. In contrast, neural measures of information processing in emotion regulation choice may serve as predictors of internal preferences for one way to cognitively regulate emotions over another.

Our findings concerning the consequences of regulatory-choices showed the expected enhanced attenuation of implementation-LPP amplitudes and self-reported arousal ratings for distraction relative to reappraisal-chosen implementation. These converging results reflect the notion that the LPP is highly sensitive to the level of arousal elicited by emotional stimuli (Hajcak *et al.*, 2010; Weinberg and Hajcak, 2010). Additionally, both the LPP and the arousal measures conceptually reflect the degree of activation of the defensive system, which corresponds, according to some theories, to emotional-intensity (Bradley *et al.*, 2001). However, the self-reported unpleasantness results were not consistent with the implementation-LPP and the arousal results. Specifically, distraction, as compared with reappraisal-choice, resulted in decreased attenuation of reported unpleasantness post-implementation. This pattern of results may reflect the notion that while distraction involved producing neutral but not positive thoughts, reappraisal may have involved reinterpreting negative emotional stimuli as more positive (e.g. 'this man would eventually recover from his wounds'. See also Parkinson and Totterdell, 1999; McRae *et al.*, 2010).

Several limitations of this study should be mentioned. First, we did not measure subjective ratings of stimuli's emotional-intensity on a trial-by-trial basis, before participants made their regulatory-choices. It could be argued that using this measure as a predictor of regulatory-choices could have further improved the prediction of regulatory-choices. Although possible, individual's self-reported emotional-intensity ratings do not represent underlying online processing of intensity. Moreover, having participants explicitly rate their perceived intensity in each trial may increase the saliency of this measure and bias subsequent regulatory-choices.

Second, since we observed greater pre-choice-LPPs for distraction relative to reappraisal choice, it could be argued that the greater subsequent reduction in implementation-LPPs during distraction relative to reappraisal was due to regression to the mean. More broadly, an exclusive regression to the mean argument would predict that the higher the pre-choice-LPPs are, the greater reduction in implementation-LPPs would be observed. However, the actual observed means suggest that at least in some instances this is not the case. For example, while pre-choice-LPPs for high-intensity reappraisal-choice ($M = 6.02$) were higher than those of low-intensity distraction-choice ($M = 5.28$), less subsequent reduction was observed in implementation-LPPs of high-intensity reappraisal-choice ($M = 2.29$), relative to low-intensity distraction-choice ($M = 2.88$). In general, when participants freely choose between regulatory strategies, it is impossible to control for initial intensity differences in distraction *vs* reappraisal chosen stimuli. Therefore, initial intensity differences could influence post-choice implementation findings. However, similar implementation results were obtained in a study that did not involve regulatory-choices, and thus controlled for initial intensity differences by randomly assigning pictures to regulatory conditions (Shafir *et al.*, 2015).

Acknowledgements

We wish to thank Pavel Goldstein and Yoav Kessler for statistical consultation, Shreya Lakhan Pal and Dustin Goerlitz for research assistance, and the two Reviewers, Joseph Hilgard and Stefan Wiens, for their very helpful input.

Funding

G. S. is supported by the Israel Science Foundation (Grant No. 1130/16).

Supplementary data

Supplementary data are available at *SCAN* online.

Conflict of interest. None declared.

References

Aldao, A., Nolen-Hoeksema, S. (2013). One versus many: capturing the use of multiple emotion regulation strategies in response to an emotion-eliciting stimulus. *Cognition and Emotion*, **27**(4),753–60.

Aldao, A., Tull, M.T. (2015). Putting emotion regulation in context. *Current Opinion in Psychology*, **3**, 100–7.

Barr, D.J., Levy, R., Scheepers, C., Tily, H.J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, **68**(3), 255–78.

Blechert, J., Sheppes, G., Di Tella, C., Williams, H., Gross, J.J. (2012). See what you think: reappraisal modulates behavioral and neural responses to social stimuli. *Psychological Science*, **23**(4), 346–53.

Bonanno, G.A., Burton, C.L. (2013). Regulatory flexibility: an individual differences perspective on coping and emotion regulation. *Perspectives on Psychological Science* **8**(6), 591–612.

Bonanno, G.A., Papa, A., O'Neill, K., Westphal, M., Coifman, K. (2004). The importance of being flexible the ability to both enhance and suppress emotional expression predicts long-term adjustment. *Psychological Science*, **15**(7), 482–7.

Bradley, M.M., Codispoti, M., Cuthbert, B.N., Lang, P.J. (2001). Emotion and motivation I: defensive and appetitive reactions in picture processing. *Emotion*, **1**(3), 276–98.

Cowan, N. (2001). The magical number 4 in short-term memory: a reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, **24**(1), 87–114.

Cumming, G. (2013). The new statistics: why and how. *Psychological Science*, **25**(1), 7–29.

Delorme, A., Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, **134**(1), 9–21.

Dennis, T.A., Hajcak, G. (2009). The late positive potential: a neurophysiological marker for emotion regulation in children. *Journal of Child Psychology and Psychiatry*, **50**(11), 1373–83.

Denny, B.T., Inhoff, M.C., Zerubavel, N., Davachi, L., Ochsner, K.N. (2015). Getting over it: long-lasting effects of emotion regulation on amygdala response. *Psychological Science*, **26**(9), 1377–88.

Dienes, Z. (2008). *Understanding Psychology as a Science: An Introduction to Scientific and Statistical Inference*. London, England: Palgrave Macmillan.

Dixon-Gordon, K.L., Aldao, A., De Los Reyes, A. (2015). Emotion regulation in context: examining the spontaneous use of strategies across emotional intensity and type of emotion. *Personality and Individual Differences*, **86**, 271–6.

Fellows, L.K. (2004). The cognitive neuroscience of human decision making: a review and conceptual framework. *Behavioral and Cognitive Neuroscience Reviews*, **3**(3), 159–72.

Fehr, E., Rangel, A. (2011). Neuroeconomic foundations of economic choice—recent advances. *The Journal of Economic Perspectives*, **25**(4), 3–30.

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

Gross, J.J. (2015). Emotion regulation: Current status and future prospects. *Psychological Inquiry*, **26**, 1–26.

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

Hajcak, G., MacNamara, A., Olvet, D.M. (2010). Event-related potentials, emotion, and emotion regulation: an integrative review. *Developmental Neuropsychology*, **35**(2), 129–55.

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

Hay, A.C., Sheppes, G., Gross, J.J., Gruber, J. (2015). Choosing how to feel: Emotion regulation choice in bipolar disorder. *Emotion* **15**(2), 139–45.

Kable, J.W., Glimcher, P.W. (2009). The neurobiology of decision: consensus and controversy. *Neuron*, **63**(6), 733–45.

Lance, C.E., Vandenberg, R.J. (2009). *Statistical and Methodological Myths and Urban Legends: Doctrine, Verity and Fable in the Organizational and Social Sciences*. New York: Taylor & Francis.

Lang, P., Bradley, M., Cuthbert, B. (2008). *International Affective Picture System (IAPS): Affective Ratings of Pictures and Instruction Manual. Technical Report*, A–8, Gainesville, FL: University of Florida.

Levy, D.J., Glimcher, P.W. (2012). The root of all value: a neural common currency for choice. *Current Opinion in Neurobiology*, **22**(6), 1027–38.

Levy-Gigi, E., Bonanno, G.A., Shapiro, A.R., Richter-Levin, G., Keri, S., Sheppes, G. (2016). Emotion regulatory flexibility sheds light on the elusive relationship between repeated traumatic exposure and posttraumatic stress disorder symptoms. *Clinical Psychological Science*, **4**(1), 28–39.

Lopez-Calderon, J., Luck, S. (2014). ERPLAB: an open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience*, **8**, 213.

Luck, S.J. (2014). *An Introduction to the Event-Related Potential Technique*, 2nd edn. Cambridge, MA: MIT Press.

Macnamara, A., Ochsner, K.N., Hajcak, G. (2011). Previously reappraised: the lasting effect of description type on picture-elicited electrocortical activity. *Social Cognitive and Affective Neuroscience*, **6**(3), 348–58.

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

Mennes, M., Wouters, H., Vanrumste, B., Lagae, L., Stiers, P. (2010). Validation of ICA as a tool to remove eye movement artifacts from EEG/ERP. *Psychophysiology*, **47**(6), 1142–50.

Moran, T.P., Jendrusina, A. a., Moser, J.S. (2013). The psychometric properties of the late positive potential during emotion processing and regulation. *Brain Research*, **1516**, 66–75.

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

Nisbett, R.E., Wilson, T.D. (1997). Telling more than we can know: verbal reports on mental processes. *Psychological Review*, **84**(3), 231–59.

Padoa-Schioppa, C. (2011). Neurobiology of economic choice: a good-based model. *Annual review of neuroscience*, **34**, 333–59.

Parkinson, B., Totterdell, P. (1999). Classifying affect-regulation strategies. *Cognition and Emotion*, **13**(3), 277–303.

Paul, S., Simon, D., Kniesche, R., Kathmann, N., Endrass, T. (2013). Timing effects of antecedent- and response-focused emotion regulation strategies. *Biological Psychology*, **94**(1), 136–42.

Rangel, A., Camerer, C., Montague, P.R. (2008). A framework for studying the neurobiology of value-based decision making. *Nature Reviews Neuroscience*, **9**(7), 545–56.

Ravaja, N., Somervuori, O., Salminen, M. (2013). Predicting purchase decision: The role of hemispheric asymmetry over the frontal cortex. *Journal of Neuroscience, Psychology, and Economics*, **6**(1), 1–13.

Reisenzein, R. (1994). Pleasure-arousal theory and the intensity of emotions. *Journal of Personality and Social Psychology*, **67**(3), 525–39.

Rosenthal, R., Rosnow, R.L. (2009). *Artifacts in Behavioral Research: Robert Rosenthal and Ralph L. Rosnow's Classic Books: A Re-Issue of Artifact in Behavioral Research, Experimenter Effects in Behavioral Research and the Volunteer Subject*. New York: Oxford University Press.

Scheibe, S., Sheppes, G., Staudinger, U. M. (2015). Distract or reappraise? Age-related differences in emotion-regulation choice. *Emotion* **15**(6), 677–81.

Schönfelder, S., Kanske, P., Heissler, J., Wessa, M. (2014). Time course of emotion-related responding during distraction and reappraisal. *Social Cognitive and Affective Neuroscience*, **9**(9), 1310–9.

Shafir, R., Schwartz, N., Blechert, J., Sheppes, G. (2015). Emotional intensity influences pre-implementation and implementation of distraction and reappraisal. *Social Cognitive and Affective Neuroscience*, **10**, 1329–37.

Sheppes, G., Brady, W.J., Samson, A.C. (2014b). In (visual) search for a new distraction: the efficiency of a novel attentional deployment versus semantic meaning regulation strategies. *Frontiers in Psychology*, **5**, 346.

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

Sheppes, G., Levin, Z. (2013). Emotion regulation choice: selecting between cognitive regulation strategies to control emotion. *Frontiers in Human Neuroscience*, **7**, 179.

Sheppes, G., Meiran, N. (2007). Better late than never? On the dynamics of online regulation of sadness using distraction and cognitive reappraisal. *Personality & Social Psychology Bulletin*, **33**(11), 1518–32.

Sheppes, G., Scheibe, S., Suri, G., Gross, J.J. (2011). Emotion-regulation choice. *Psychological Science*, **22**(11), 1391–6.

Sheppes, G., Scheibe, S., Suri, G., Radu, P., Blechert, J., Gross, J.J. (2014a). Emotion regulation choice: a conceptual framework and supporting evidence. *Journal of Experimental Psychology: General*, **143**(1), 163–81.

Telpaz, A., Webb, R., Levy, D.J. (2015). Using EEG to predict consumers' future choices. *Journal of Marketing Research*, **52**(4), 511–29.

Thiruchselvam, R., Blechert, J., Sheppes, G., Rydstrom, A., Gross, J.J. (2011). The temporal dynamics of emotion regulation: an

EEG study of distraction and reappraisal. *Biological Psychology*, **87**(1), 84–92.
Van der Tweel, I. (2005). Repeated looks at accumulating data: to correct or not to correct? *European Journal of Epidemiology*, **20**(3), 205–11.
Van Dillen, L.F., Koole, S.L. (2007). Clearing the mind: a working memory model of distraction from negative mood. *Emotion* **7**(4), 715–23.
Webb, T., Gallo, I.S. (2012). Effective regulation of affect: An action control perspective on emotion regulation. *European Review of Social Psychology*, **23**(1), 143–86.
Weinberg, A., Hajcak, G. (2010). Beyond good and evil: the time-course of neural activity elicited by specific picture content. *Emotion*, **10**(6), 767–82.
Wilson, T.D., Gilbert, D.T. (2008). Explaining away: A model of affective adaptation. *Perspectives on Psychological Science*, **3**(5), 370–86.