Emotion regulation in adolescents: An ERP study

Alex Desatnik[a,*], Tarik Bel-Bahar[b], Tobias Nolte[c], Michael Crowley[d], Peter Fonagy[a], Pasco Fearon[a]

[a] Research Department of Clinical, Educational and Health Psychology, University College London & The Anna Freud National Centre for Children and Families, London, United Kingdom
[b] Center for Consciousness Science, Department of Anesthesiology, University of Michigan Medical School, Ann Arbor, MI, USA
[c] Wellcome Trust Centre for Neuroimaging, University College London, London, United Kingdom
[d] Child Study Center, Yale University, New Haven, USA

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ABSTRACT

Aims: The use of emotion regulation strategies can reduce the intensity of negative emotional experiences. Event related potentials (ERPs), specifically the late positive potential (LPP), are known to be sensitive to this modulation in adults. This is the first study to explore the neural correlates of expressive suppression in adolescents. We sought to replicate previous findings from emotion regulation studies with adult populations, show that the LPP can be modulated by expressive suppression in healthy adolescents, and examine the influence of age on LPP changes.

Method: ERPs of 53 healthy adolescents (12–17 years old) performing an emotion regulation task (expressive suppression) were recorded.

Results: Expressive suppression altered the LPP in adolescents with both increases and decreases noted depending on time window and recording site. The LPP during expressive suppression was decreased with increasing age.

Conclusions: The findings suggest that 1) the LPP is an effective tool to study processes associated with emotion regulation in adolescents, and 2) expressive suppression, in terms of its neural indicators, seems to become more effective with age. The nature and utility of expressive suppression as a specific form of emotion regulation in adolescents are discussed.

1. Introduction

The ability to regulate one's emotions is considered essential for mental health (Berking, Wirtz, Svaldi & Hofmann, 2014; Sheppes, Suri & Gross, 2015; Tortella-Feliu, Balle & Sesé, 2010; Van Rheenen & Rossell, 2014). Difficulties in emotion regulation are a key feature characterizing multiple psychopathologies across the lifespan (Aldao, Nolen-Hoeksema & Schweizer, 2010; American Psychiatric Association, 2013; Fernandez, Jazaieri & Gross, 2016; Sheppes et al., 2015). Emotion regulation is thought to involve interactions between multiple cognitive-affective-behavioral processes and is widely researched in adults (e.g., Butler & Randall, 2013; Campbell-Sills & Barlow, 2007) and children (e.g., Adrian, Zeman & Veits, 2011; Gresham & Gullone, 2012; Kim-Spoon, Cicchetti & Rogosch, 2013; Lewis, Lamm, Segalowitz, Stieben & Zelazo, 2006; Zeman, Cassano, Perry-Parrish, & Stegall, 2006). Adolescence is a developmental phase which presents with increased demands to regulate one's emotions and

behavior during a time characterised by multiple neurophysiological, psychological, and social changes (Casey, 2015; Fuhrmann et al., 2015; Shulman, Harden, Chein & Steinberg, 2014). Despite this, only a relatively small number of studies, using mainly self-report methodologies, have explored emotion regulation during adolescence (Gresham & Gullone, 2012; Penela, Walker, Degnan, Fox & Henderson, 2015; Silvers et al., 2012; Zimmerman & Iwanski, 2014), and the associations of emotion regulation with psychopathology (Esbjørn, Bender, Reinholdt-Dunne, Munck & Ollendick, 2012; Garnefski, Kraaij & van Etten, 2005; Silk, Steinberg & Morris, 2003). Thus, the empirical study of emotion regulation processes in adolescence requires continued development.

1.1. Emotion generation and regulation strategies

In the process model of emotion regulation (Gross, 2015; Sheppes et al., 2015), emotional experience and expressions arise as an

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individual attends to and interprets the current situation in terms of relevance to his goals. The generation of emotion and emotion regulation is considered to be complex dynamic processes that unfold over time. While emotion generation is considered to occur mainly in the earlier stages of this model, the emotion regulation strategies subsequently chosen can give rise to a new cycle of emotion experiences and later regulation attempts, thus resulting in continuous multiple interactions across stages. These processes are impacted by the way other people react and the general situation. Overall the processes described appear to include a wide variety of emotion regulation dynamics which differ based on time, interpersonal context and environmental feedback.

Five stages of emotional regulation processes are suggested by Gross: situation selection, situation modification, attentional deployment, cognitive change (e.g reappraisal), and response modulation (e.g suppression). Each of these processes is thought to differ in relation to the point in time at which they can be deployed and in the primary impact they have on the emotion generation process. The first four are considered to be antecedent focused and influence the emotion-generation cycle before emotions are fully expressed. Response modulation is considered to be focused on behavioral expressions, occurring once earlier processes such as situation selection and attentional deployment have been deployed (e.g., covering or hiding already generated emotions). As suggested by Gross and Feldman Barrett (2011), there are various theoretical perspectives on emotion (e.g., basic, appraisal, social construction) that all suggest that emotion-related episodes unfold over time. However, Gross and Feldman-Barrett note that the same emotion-related process can be considered generative or regulative depending on whether they occur towards the beginning or end of an emotional episode.

There is no a priori assumption about a particular form of emotion regulation being "good" or "bad" (Thompson, Lewis & Calkins, 2008). Some researchers have tended to make the distinction between cognitive change (reappraisal) as an adaptive response, and response modulation (suppression) as having negative physiological and interpersonal consequences (Gross, 1998a, 1998b; Sheppes et al., 2015). Other recent studies tend to show that whether an emotion regulation strategy, such as expressive suppression, is effective or adaptive is context dependent (Paul, Simon, Kniesche, Kathmann & Endrass, 2013; Zimmerman & Iwanski, 2014; English et al., 2016). One might say that an excessive reliance on any one emotion regulation strategy, or disregarding the situational demands and context, may lead to adverse consequences. For example, persistent or chronic situation selection, such as avoiding difficult emotionally arousing social situations may give rise to social anxiety. On the other hand, attentional deployment may in some circumstances lead one to miss important situational and social information (Campbell-Sills & Barlow, 2007; Werner & Gross, 2010).

1.2. Neural correlates of emotion generation

While the neuroscientific investigation of emotion often uses functional magnetic resonance imaging (fMRI), the use of the electroencephalogram (EEG) is also essential to understand brain dynamics associated with emotion generation and regulation. Averaged trials of EEG time locked to stimulus events (e.g., images, sounds, words) are known as event related potentials (ERPs), which reflect event-related synchronous activity of neuronal ensembles recorded by scalp electrodes. EEG allows for millisecond-level resolution, which is crucial for studying the fast temporal brain dynamics of emotion generation and regulation (Hajcak, MacNamara & Olvet, 2010). Many ERP studies looking at emotional processing and regulation have focused on the late positive potential (LPP), which is a midline ERP observable around 300 ms after stimulus onset and which lasts for at least several hundred milliseconds (Hajcak et al., 2010). The LPP has been shown to increase significantly in response to emotional images compared to neutral

images (including scenes and faces with neutral content, Kujawa, Klein & Hajcak, 2012). However, some studies show that the LPP may be driven primarily by the arousal content of emotional images, as the LPP was not sensitive to the specific valence (positive vs negative) of the presented images (e.g., Cuthbert, Schupp, Bradley, Birbaumer & Lang, 2000; Keil, Moratti & Stolarova, 2003). The modulation of the LPP by emotional stimuli is most visible in occipital, parietal, and central EEG channels (Hajcak et al., 2010). It is thought that LPP enhancement observed when emotional stimuli are presented may reflect the downstream effects of early amygdala activation in the visual occipital cortex (de Rover et al., 2012).

1.3. Neural correlates of emotion regulation

In addition to being sensitive to the emotional content of stimuli in general, it is suggested that the time course of the LPP is an index of emotion regulation processes. Several studies have shown LPP sensitivity to various emotion regulation strategies such as reappraisal (Foti & Hajcak, 2008; Hajcak & Nieuwenhuis, 2006; Paul et al., 2013; Thiruchselvam, Blechert, Sheppes, Rydstrom & Gross, 2011), distraction (Paul, Kathmann & Riesel, 2016; Thiruchselvam et al., 2011; Uusberg, Thiruchselvam & Gross, 2014), and suppression (Moser, Hajcak, Bukay & Simons, 2006; Paul et al., 2013). Distraction (Paul et al., 2013; Thiruchselvam et al., 2011), expressive suppression (Paul et al., 2013) and cognitive suppression (Moser et al., 2006) seem to influence the earlier time windows of the LPP starting around 300 ms. Other studies have shown that cognitive reappraisal can influence both late (Paul et al., 2013; Thiruchselvam et al., 2011), and earlier time windows (Hajcak & Nieuwenhuis, 2006; Krompinger, Moser & Simons, 2008; Wessing, Rehbein, Postert, Fürniss & Junghöfer, 2013). It has been suggested that the earlier positivity recorded in these studies is possibly associated with attending to the stimulus, while the later positivity reflects the cognitive-semantic elaboration of the stimulus (Schupp, Flaisch, Stockburger & Junghöfer, 2006).

1.4. Neural correlates of emotion generation and regulation in children and adolescents

Childhood and adolescence involve a range of normative brain and psychological changes in terms of emotional experience, regulation, and behavior (Casey, 2015; Fuhrmann et al., 2015; Stephanou et al., 2016). Several brain imaging (e.g., Kadosh et al., 2016; McRae et al., 2012; Perlman & Pelphrey, 2011; Vijayakumar et al., 2014) and behavioral studies (e.g., Brenning, Soenens, Van Petegem & Vansteenkiste, 2015; Tottenham, Hare & Casey, 2011; Zimmerman & Iwanski, 2014) suggest that emotion regulation improves with brain development. The linear improvement with age between adolescents and young adults in emotion regulation was associated with the differential activity in regions closely associated with reappraisal in adults, including greater left ventrolateral prefrontal cortex (PFC) activity, and decreased temporal-occipital and amygdala activity (McRae et al., 2012; Silvers et al., 2016; Stephanou et al., 2016). Further, there is evidence that emotion regulation becomes more selective and effective with age, as adults adapt the way in which they manage emotions based on experience and the demands of the situation (Carstensen, Fung & Charles, 2003).

Although there are a large number of brain imaging studies with children using emotional stimuli such as faces and other images, only a small number of studies have focused on the LPP in children, and fewer still on emotion regulation tasks. Hajcak and Dennis (2009) used age appropriate images from the International Affective Picture System (IAPS; Lang, Bradley & Cuthbert, 2008) and found that, similarly to adults, children (5–8 years old) produced increased LPP in response to emotional images relative to neutral ones. However, in this age group LPP activity seemed more focused at occipital regions as opposed to more centrally-focused LPPs found in adults. Dennis and Hajcak (2009) also demonstrated that emotion regulation strategies modulated the

LPP in children (5–10-year-olds) with the LPP being significantly lower following neutral compared to negative interpretations of the images. This was only the case for the middle LPP time window (600–1000 ms), suggesting that, cognitive reappraisal in children has an impact relatively late in the emotion generation process, although other studies have shown reappraisal effects in early LPP time windows with both adults (e.g. Hajcak & Nieuwenhuis, 2006; Krompinger et al., 2008) and children (Wessing et al., 2015). In contrast to the findings of Dennis and Hajcak (2009), DeCicco, Solomon, and Dennis, (2012) showed that while the LPP was indeed larger in response to unpleasant versus neutral images in children (5–7 year olds) the LPP was not sensitive to reappraisal. The authors explained this discrepancy with previous findings by suggesting that the use of reappraisal is still developing in younger children and that they are less able to use this strategy to regulate their emotions. This discrepancy also highlighted the importance of ensuring that the sometimes complex instructions involved in regulation tasks (e.g. reappraisal, distraction, etc.) are presented in an age-appropriate way so that the absence of evidence for emotion regulation modulation is not simply a result of a child participant's failure to understand or enact the task requirements. Overall, previous child studies have mostly used cognitively demanding and complex regulation tasks. There is also a lack of child studies examining relatively simpler strategies such as simple distraction or expressive suppression.

The number of LPP studies of emotion processing in adolescence is limited in comparison to child and adult studies. Zhang et al. (2012) demonstrated that in adolescents (11–17 years old) the LPP is modulated by emotional images from the Chinese affective picture system, with emotional images eliciting larger LPP than neutral ones, and hence showing results similar to findings with adults. In another study, Zhang et al. (2013) found that individual differences in harm avoidance in adolescents (11–19 years old) predicted LPP amplitudes for positive and negative images, but not for neutral ones. Another study found that adolescent criminal offenders (13–17 years old), showed decreased LPP for negative images; however, the non-offenders showed larger LPP amplitudes in response to unpleasant compared to both neutral and positive stimuli while no such emotional LPP modulation observed in the offender group (Pincham, Bryce & Fearon, 2015). Further, higher LPP during passive viewing of emotional stimuli has been associated with psychiatric symptoms in adolescence (Kujawa et al., 2015; Nelson, Perlman, Hajcak, Klein & Kotov, 2015) and there is evidence of LPP test-retest stability (Kujawa et al., 2013) in children and adolescents.

While developmental research suggests that emotion regulation is undergoing significant development during adolescence (Zimmerman & Iwanski, 2014), little is known about the neural and behavioral correlates of various forms of emotion regulation in adolescents. To date only one LPP study examined emotion regulation in adolescents. Zhang et al. (2014) examined LPP modulation with a distraction condition and reported that LPP amplitudes to negative pictures, relative to positive pictures, were reduced during distraction. Counting backwards by three reduced LPP to only negative pictures in younger adolescents, but it reduced LPP for both positive and negative pictures in the older adolescents. However, the chosen distraction strategy was relatively complex.

It is therefore of importance to further explore the effects of various emotion regulation strategies in adolescents, especially strategies that may be more easily deployed and less cognitively demanding. Using such strategies (i.e., expressive suppression) may have the benefits of simple regulation tasks and unambiguous instructions, thus helping to reduce experimental bias associated with cognitive effort. Several adult studies had investigated the effects of expressive suppression (Cutuli, 2014). While in Gross's model (Sheppes et al., 2015) expressive suppression is thought of as a regulatory strategy deployed after an emotion has been generated, other studies suggest that expressive suppression might also have an effect earlier on in the emotion generation cycle. Specifically Paul et al. (2013), showed that expressive

suppression modulated the LPP from the very beginning of the LPP. They suggested that expressive suppression instructions may be used as a preparatory regulation tool to prevent the elicitation of an emotional response before the onset of stimuli and regardless of its content.

Yet no studies to date have specifically examined expressive suppression effects on the LPP in an adolescent sample. Expressive suppression is an important regulation strategy that has received relatively little research attention even though it may involve brain networks that are different from those activated by reappraisal strategies (Morawetz, Bode, Derntl & Heekeren, 2016). It is a strategy that may be used in situations when it is necessary to conceal either positive or negative expressions, often in social contexts (English et al., 2016). Much like reappraisal, expressive suppression is likely to be influenced by developmental maturation (Gullone et al., 2016). It is also possible that due to the significant importance of peer relationships in adolescence (Collins & Laursen, 2004; Giordano, 2003) expressive suppression is a particularly relevant emotion regulation strategy. Overall, expressive suppression is a unique subject of study for a better understanding of both adaptive and maladaptive emotion regulation strategies, and whether they become easier with maturation.

1.5. Aims of the present study

While developmental research suggests that emotion regulation is undergoing significant development during adolescence (Gullone et al., 2010; Zimmerman & Iwanski, 2014), little is known about the neural and behavioral correlates of various forms of emotion regulation in adolescents. The current study had three aims. First, we expected to replicate previous findings from adult studies by showing that emotion regulation (namely expressive suppression) reduces LPP amplitude in adolescents. Second, we expected to show that increasing age is linked to less effortful emotion regulation, as reflected by decreased LPP amplitudes in older participants. Third, due to topographic differences found in the LPP between children and adults we explored LPP variability during emotion regulation in this age group by examining differences across occipital, parietal and central-parietal midline channels where LPP was previously reported in child and adult populations (Hajcak & Dennis 2009; Hajcak & Nieuwenhuis, 2006).

Due to the relatively broad age range (12–17) of participants included in this study, the expressive suppression protocol used was as simple as possible, benefiting from clear instructions that could easily be followed by an adolescents of any age, minimizing the impact of potential confounds related to cognitive load. This protocol has been used in adult populations and shown to be effective in attenuating the LPP at the earlier time windows, similarly to other "pre-emptive" strategies (Paul et al., 2013).

2. Method

2.1. Participants

Participants were fifty-three 12–17 year old adolescents (M = 14.43 years, SD = 1.74); 29 females and 24 males. There were seventeen 12–13 year olds, twenty 14–15 year olds, and sixteen 16–17 year olds. The participants were recruited from a diverse community in North West London and all were fluent in speaking and reading in English for at least five years. All were right handed with no chronic illnesses, normal or corrected to normal vision, and no self-reported or parent-reported history of drug or alcohol dependency or diagnosed psychopathology. The participants were paid £20 as remuneration for their participation in the experiment.

2.2. Ethical considerations

The parents of all participants who were younger than 16 years old and adolescents aged 16 and older were required to sign an informed

consent form that detailed the study rationale and all the procedures. Parents completed the screening questions for participants under 16 years of age. Participants over sixteen completed the screening questionnaires themselves. Both the parents and the participants were clearly informed that they may withdraw from any part of the study at any point. The study has been granted ethical approval by UCL Research Ethics Committee (ID Number: 1908/001).

2.3. Stimuli

The stimuli were presented on a black background of a 15 inch computer monitor using Eprime 2.0 software. 60 unpleasant and 30 neutral developmentally appropriate images were selected from the IAPS pool (Lang et al., 2008). The 9 × 7 cm images were presented at the centre of the screen at a 65 cm viewing distance. Each image covered the horizontal visual angle of 7.9° and vertical visual angle of 6.1°. We resized the images so that they were centred on the screen, so as to make it easier for participants to fixate on the image without scanning the full screen and thus preventing larger eye movements.

2.4. Procedure

After obtaining consent from the participants, an EEG net was applied and the participants were given detailed instructions. The experiment consisted of two blocks: in the first block (passive viewing) the participants were instructed to view 30 unpleasant (negative view condition) and 30 neutral (neutral view condition) images presented in random order. This was followed by the expressive suppression condition. In the instructions, participants were asked not to show their feelings, so that any person watching them would have no idea what they were feeling. The participants were shown cameras at the bottom of the computer screen and informed that the experimenters would be watching their responses. Videos were not recorded and used only for 1) monitoring attentiveness in participants and 2) to provide the manner by which the participant would be "watched for signs of emotion" during the expressive suppression task. They were then asked to tell the experimenter what was required of them during the task. Then participants were presented with the expressive suppression block consisting of 30 negative images. For all conditions, participants completed three practice trials which they were allowed to repeat if they wished.

The present study did not counterbalance the passive viewing and expressive suppression conditions. This is in line with previous studies investigating the effects of expressive suppression that did not use counterbalancing of conditions (Gross & Levenson, 1993; Murata, Moser & Kitayama, 2012; Musser et al., 2011). Conditions were presented in a fixed non-counterbalanced order to minimize potential carry-over effects (Murata et al., 2012; Musser et al., 2011) between conditions, i.e., to avoid participants continuing to suppress in the passive view condition after having done the suppression condition first. Other influences that may have been minimized with the current design include task-switching or cognitive load effects between conditions (Murata et al., 2012; Musser et al., 2011). Further, possible benefits from doing passive viewing first include familiarizing participants with the general requirements of the image-viewing task (Gross & Levenson, 1993; Musser et al., 2011) and maximizing the potential effects of the suppression challenge (Musser et al., 2011).

Following the completion of the task, the participants were shown 30 random positive images from the IAPS in order to improve their mood in case it was affected by the images they had seen; this last block was not recorded. After the last block the EEG net was removed and the participants were allowed to rest. During that time, the participants were asked what they were doing in the task and all the participants confirmed that they had tried to make sure the experimenters could not see what they felt from their face and (upper) body. Finally the participants were paid and debriefed.

2.5. The task

Each trial in the passive viewing block began with a white fixation cross that appeared at the centre of the screen for 500 ms, which was followed by a 500 ms blank screen, after which the neutral or unpleasant image was presented for the duration of 2000 ms, which was then followed by another 500 ms blank screen.

Each trial in the expressive suppression block began with a white fixation cross appearing at the centre of the screen for 500 ms. The cross was followed by a 2000 ms ("regulate") window during which the words "don't show" appeared on the screen in white on a black background accompanied by a male or female voice (alternating) saying "don't show". This was followed by the presentation of the unpleasant image for 2000 ms which was followed by a 500 ms blank screen. The total number of trials in this block was 30.

2.6. EEG recording and data reductions

The EEG was acquired with 128-channel HydroCel Geodesic sensor nets (Electrical Geodesics, Eugene, OR) and recorded/analysed with Net Station 4.3 software. Eye movements were recorded sensor net electrodes placed approximately 1 cm below the participants' right and left eyes.

For each subject's data the EEG was filtered with a 0.03 Hz high-pass and a 30 Hz low-pass filter. The EEG was then segmented for each trial from negative 200 ms to 1500 ms relative to the stimulus onset. Artefact detection included removing trials with amplitude changes above 150 μV across an entire segment, as well as trials with eye blinks or lateral eye movements. Standard bad channel detection and replacement was then performed. The EEG epochs were then averaged to create the stimulus-locked ERPs for each subject. The single-subject ERPs were then average referenced and baseline corrected (-200 to 0 ms). For the neutral view condition, the mean number of trials was 24.88 (SD = 4.27, range = 14–30). For the negative view condition, the mean number of trials was 23.5 (SD = 4.46, range = 14–30). For the expressive suppression condition, the mean number of trials was 26.9 (SD = 3.56, range = 16–30)

Based on previous studies (Moser et al., 2006; Hajcak & Dennis, 2009; Dennis & Hajcak, 2009), the LPP was defined as the mean amplitude in three time windows following the stimulus onset: early (350–600 ms), middle (600–1000 ms), and late (1000–1500 ms) time windows. As per these previous studies, we defined an LPP as a positive amplitude that occurs 1) after stimulus onset, 2) relative to the start of the trial, 3) can be easily seen in topomaps at posterior sites, and 4) extended from about ~300 ms to the end of the trial. ERPs were computed from three channels along the midline: central parietal (CPz), parietal (Pz) and occipital (Oz), the same channels used in previous studies (Moser et al., 2006; Hajcak & Dennis, 2009) for analyses of LPP activity. While the choice of Oz is unusual based on adult studies (Moser et al., 2006), it was selected for this study due to the LPP-like effects reported in children at occipital electrodes (Hajcak & Dennis, 2009).

3. Results

3.1. ERP results

A 3 (Channel: CPz, Pz, Oz) x 3 (Time window: early [350–600 ms], middle [600–1000 ms], late [1000–1500 ms]) x 3 (Condition: neutral view, negative view, expressive suppression) repeated measures analysis of variance (ANOVA) (see Table 1 for means and standard deviations, and Table 2 for t-test statistics) identified significant main effects of: channel $F_{(2, 51)} = 31.4$, $p < 0.001$; time window $F_{(2, 51)} = 84.32$, $p < 0.001$; and condition $F_{(2, 51)} = 14.58$, $p < 0.001$. There were significant interactions of: condition and time window $F_{(4, 49)} = 27.12$, $p < 0.001$; condition and channel $F_{(4, 49)} = 22.15$,

Table 1

Mean values and standard deviations (SD) and corresponding differences in post-hoc paired tests, between Neutral View, Negative view, and Expressive suppression trials, for every time epoch at each channel.

Time Window	Channel	Neutral View	Negative View	Expressive Suppression
Early window	CPz	−4.51	−3.82	3.16*
		(6.3 SD)	(6.02 SD)	(4.42 SD)
	Pz	5.14*	7.57*	10.96*
		(5.5 SD)	(6.83 SD)	(5.55 SD)
	Oz	14.84*	16.64*	12.72*
		(8.89 SD)	(10.96 SD)	(9.07 SD)
Middle window	CPz	−0.78*	1.44*	4.92*
		(4.59 SD)	(4.26 SD)	(3.70 SD)
	Pz	3.24*	7.64	6.84
		(4.27 SD)	(5.88 SD)	(4.97 SD)
	Oz	8.49*	11.25*	5.57*
		(6.76 SD)	(8.45 SD)	(6.11 SD)
Late Window	CPz	−0.99*	1.07*	2.96*
		(4.41 SD)	(3.66 SD)	(3.58 SD)
	Pz	1.35*	3.41	2.06
		(3.56 SD)	(4.25 SD)	(3.80 SD)
	Oz	5.02	5.41	0.93*
		(5.58 SD)	(6.43 SD)	(4.52 SD)

Note: * = condition is significantly different from both other conditions.

$p < 0.001$; and condition, time window and channel $F_{(8, 45)} = 10.27$, $p < 0.001$. Post-hoc comparisons were Bonferroni-corrected. The significant threshold was set to 0.05. The above results confirm the impression gathered from Figs. 1 and 2 that the three experimental conditions clearly differ between each other across a majority of recording sites and time windows. Table 1 presents the results of the post hoc paired tests conducted for each condition, at all time windows, across all channels.

At CPz channel, expressive suppression enhanced the LPP in all three time windows compared to both neutral and negative view conditions. Further, the negative view amplitude at middle and late windows was higher than in the neutral view condition. Compared to the early time window, there were relative positive-going increases in amplitudes in all three conditions. The neutral view condition had only negative (below-zero) amplitude values across all time windows, the negative view condition only had positive (above-zero) amplitudes after the early time window, and only the expressive suppression condition had positive amplitude values throughout all time windows.

At the Pz channel, expressive suppression enhanced the LPP in the early time window compared to both neutral and negative view conditions. The mean amplitudes in the middle time window for expressive suppression condition was not significantly different from the negative view condition, and both were significantly higher than the neutral view condition amplitude. There were no differences in late window for LPP amplitudes between the neutral view and expressive suppression conditions, whereas the negative view condition led to significantly higher LPP amplitudes than the neutral view condition. Further, the negative view amplitude at the early time window was higher than in the neutral view condition. In addition, LPP amplitudes did not differ in the late time window between the negative view and the expressive suppression conditions.

At the Oz channel, expressive suppression reduced the LPP in all three time windows compared to both neutral and negative view conditions. The three conditions differed from one another in both early and middle time windows. The neutral view condition led to a lower amplitude than the negative view condition in these two time windows. In the late time window there was no difference in amplitudes between the neutral and negative view conditions, whereas the expressive suppression condition amplitude remained lower than the other two conditions.

3.2. Relationship between LPP and age and gender

In order to examine how the changes in LPP relate to age, Pearson correlations between the mean LPP amplitude and age were calculated for each condition and time window. The correlations between LPP amplitudes and gender were computed in the same manner. The p-
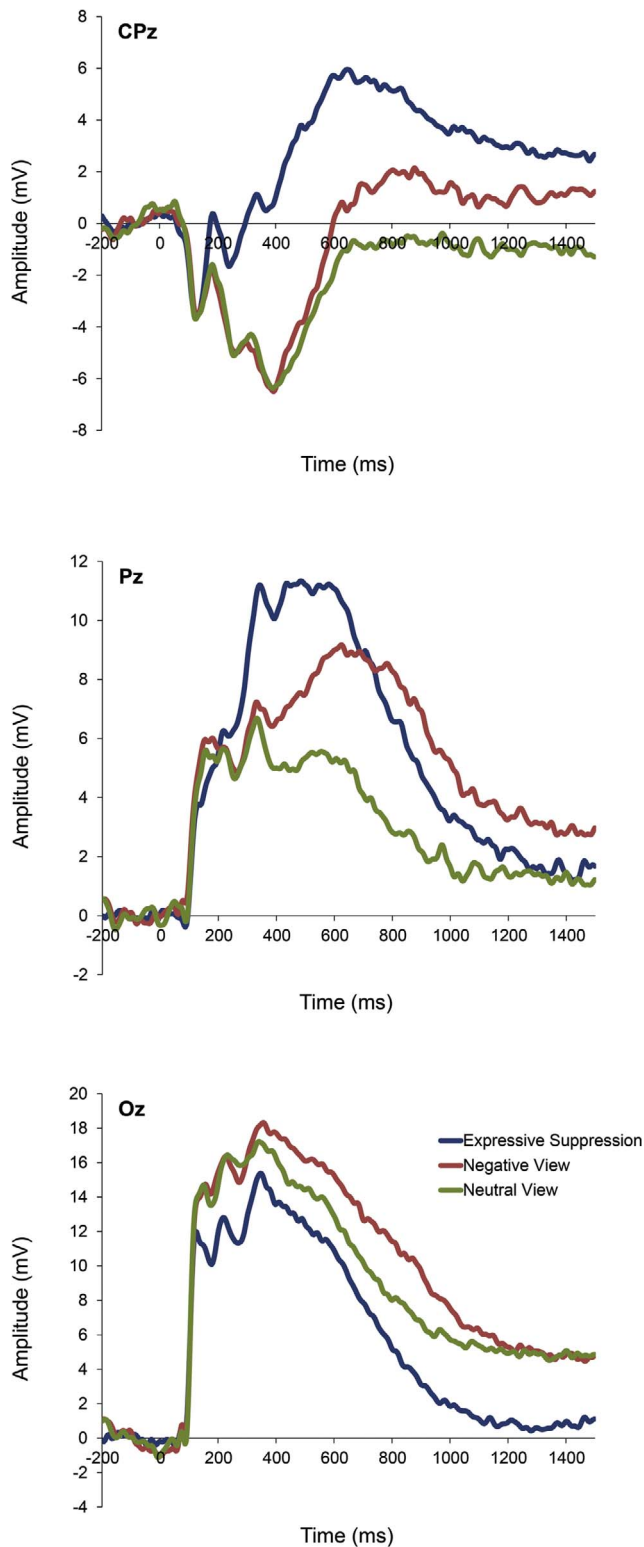
Table 2

Post-hoc pairwise contrasts across time windows, channels, and conditions.

Time Window	Channel	Pairwise contrast			Mean diff	Std. Error	T
Early Window	CPz	Negative	–	Neutral	0.69	0.54	1.29
		Suppression	–	Neutral	7.68	0.73	10.55***
		Suppression	–	Negative	6.99	0.73	9.61***
	Pz	Negative	–	Neutral	2.43	0.74	3.29**
		Suppression	–	Neutral	5.82	0.8	7.25***
		Suppression	–	Negative	3.38	0.76	4.45***
	Oz	Negative	–	Neutral	1.81	0.55	3.29**
		Suppression	–	Neutral	−2.11	0.71	−2.98*
		Suppression	–	Negative	−3.92	0.67	−5.89***
Middle Window	CPz	Negative	–	Neutral	2.24	0.54	4.13***
		Suppression	–	Neutral	5.71	0.72	7.97***
		Suppression	–	Negative	3.47	0.74	4.70***
	Pz	Negative	–	Neutral	4.4	0.7	6.31***
		Suppression	–	Neutral	3.6	0.79	4.54***
		Suppression	–	Negative	−0.8	0.74	−1.09
	Oz	Negative	–	Neutral	2.76	0.62	4.44***
		Suppression	–	Neutral	−2.92	0.77	−3.82**
		Suppression	–	Negative	−5.68	0.69	−8.18***
Late Window	CPz	Negative	–	Neutral	2.07	0.6	3.43**
		Suppression	–	Neutral	3.96	0.74	5.38***
		Suppression	–	Negative	1.9	0.75	2.53*
	Pz	Negative	–	Neutral	2.06	0.59	3.47**
		Suppression	–	Neutral	0.71	0.65	1.08
		Suppression	–	Negative	−1.35	0.56	−2.44
	Oz	Negative	–	Neutral	0.39	0.57	0.68
		Suppression	–	Neutral	−4.09	0.69	−5.90***
		Suppression	–	Negative	−4.48	0.64	−6.99***

Note: Bonferroni corrected significance values. * = < 0.05, ** = < 0.01, *** = < 0.001

Fig. 1. Stimulus-locked ERPs at CPz, Pz and Oz channels for Expressive Suppression, Negative View, and Neutral View conditions.
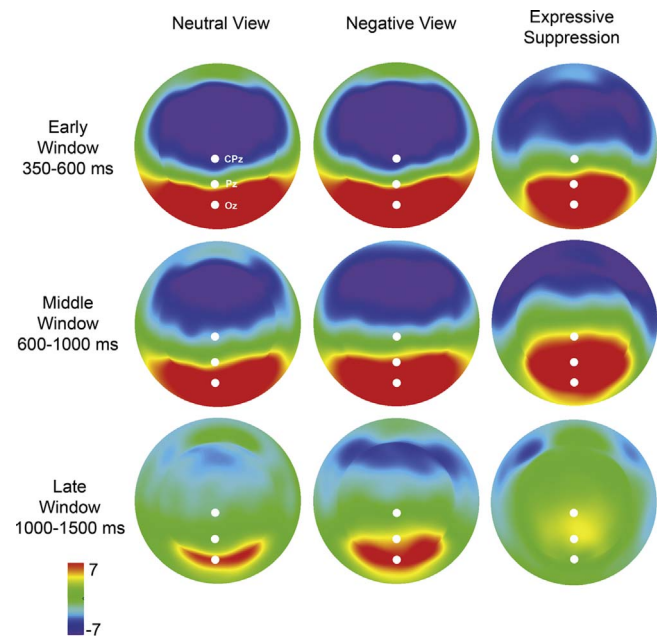

Fig. 2. Scalp topographies for expressive suppression, negative view, and neutral view conditions at early, middle, and late LPP time windows.

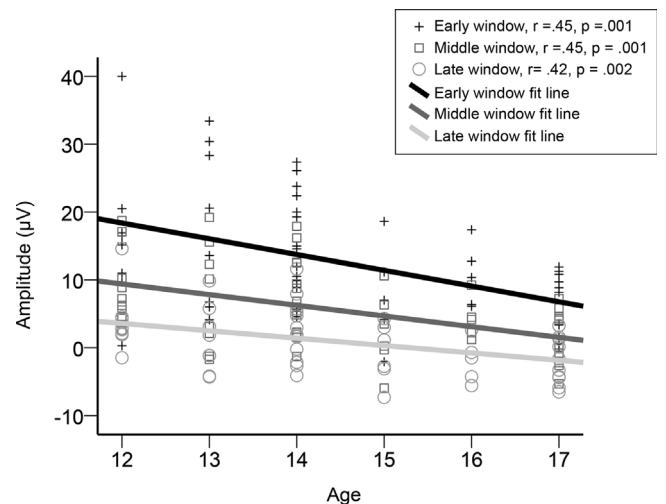**Fig. 3.** Scatterplot of correlations between Oz LPP and age.

values were corrected via Bonferroni adjustment for family-wise error.

Significant negative correlations with age that passed a Bonferroni correction (18 tests, adjusted p = 0.002) were only found for the expressive suppression condition across all time windows at the occipital (Oz) channel: early window (r = −0.44, p < 0.001); middle window 600–1000 (r = −0.45 p < 0.001); late window 1000–1500

(r = −0.42 p < 0.01) (See Fig. 3). There were no significant correlations between age and CPz amplitudes. There were several other negative correlations that were below the significance threshold following the Bonferroni correction, including negative correlations of age with negative view amplitudes at the Oz channel in the early (r = −0.34, p = 0.013), middle (r = −0.38, p = 0.005) and late (r = −0.32, p = 0.018) time windows. Further, age was negatively correlated with expressive suppression amplitudes at Pz channel in the early time window (r = −0.33, r = 0.015). There were no positive correlations approaching significance between age and LPP metrics. These results suggest that LPP decreased with increasing age.

Furthermore, Hotelling's t analysis showed that the correlations between age and the expressive suppression LPP at the early time window were significantly higher compared to those with the negative view LPP, t = 1.9, p < 0.05. This confirms the hypothesis that the amplitude decrease associated with age was related to the expressive suppression condition and not just the valence of the stimuli. In exploratory analyses we examined and found no significant point biserial correlations of gender with LPP values.

4. Discussion

The aim of the present study was to extend previous findings regarding the neural correlates of emotion regulation in early to late adolescence. This study provides new evidence that expressive suppression can alter brain activity associated with emotional responses to unpleasant stimuli in adolescents.

The present findings confirmed that, in line with previous studies (Cuthbert et al., 2000; Dillon, Cooper, Grent, Woldorff & LaBar, 2006; Foti & Hajcak, 2008; Moser et al., 2006), negative images increased the LPP compared to neutral images across all the examined channels. These results support the assumption that, as in findings from adult studies, the LPP is a valid metric to explore emotion regulation processes in adolescence. Further, we confirmed that expressive suppression in adolescents led to changes in the LPP, as has also been shown with adults and children with other emotion regulation strategies. This indicates that the LPP is sensitive to expressive suppression instructions and can be used to explore emotion regulation processes in adolescents.

Expressive suppression significantly reduced the LPP at occipital channels. Similarly to adult studies (Foti & Hajcak, 2008), in the late time window, negative images preceded by a suppression cue resulted in parietal LPPs that were not significantly different to those elicited by neutral images. The negative view condition only differed from the neutral view condition, whereas the expressive suppression condition did not differ from the neutral view. Overall these findings suggest that, similarly to adults, adolescents can successfully use emotion regulation strategies to down-regulate emotional arousal. However, our results showing differences between passive viewing and expressive suppression conditions, should be interpreted with caution due to the current study design which did not allow for counterbalancing, and in particular due to the possible confounding effects of always having the passive viewing conditions before the expressive suppression condition (i.e., condition order).

Based on visual examination of Fig. 2, at early time points in the expressive suppression condition (between 100 and 200 ms) there seems to be an amplitude decrease at Oz, and increased amplitudes at CPz and Pz. This early modulation of the ERP suggests that the specific protocol used in this study, which included a suppression cue before the onset of an image altered the neural activity soon after the start of each trial. This trend may reflect the deployment of suppression strategies from the onset of the cue and prior to the onset of the image.

While adult studies do not usually report on changes at the occipital channel, in the present study the LPP reduction during expressive suppression in the late window was pronounced, such that the LPP was lower than in the neutral view condition, possibly this late window modulation of the LPP is indexing a later cognitive process beyond the mere diminution of earlier perceptual and emotional responses. Consistent with this idea, in the late time window, at the Oz channel, there was no significant difference between the negative view and neutral view conditions, whereas the effects of expressive suppression were evident through all the three time windows. The general suppression-induced LPP decrease at Oz may reflect a modulation of visual-sensory processing by emotional regulation. It is possible that this trend is more evident in the adolescent population, as previous studies (Hajcak & Dennis, 2009; Stephanou et al., 2016; Wessing et al., 2015) have shown that the neural correlates of emotion regulation tend to be located in more occipital and posterior regions in younger participants.

At the central-parietal (CPz) channel the negative view condition did not generate an LPP (above-zero amplitude) in the early time window, but generated an LPP in the two late time windows. The expressive suppression condition resulted in an LPP in all three time windows, which was consistently higher than the negative and neutral view LPPs. The overall amplitude trend in CPz channel is similar to the one reported by Moser et al. (2006). It may be the LPP dynamics at CPz more closely reflect the attentional-cognitive demands of expressive suppression as instantiated by dorsal-parietal networks, in contrast to the more visual-perceptual processes that are likely reflected by LPP dynamics at occipital channels, although this idea warrants further investigation. Increases in early LPP windows for both Pz and CPz may both reflect an increased effort deployed during expressive suppression. It is possible that the pre-emptive nature of the expressive suppression protocol (with suppression cue before image onset) used in this study led to considerably more effort from the start of the trial.

The scalp topography changes noted in this study, particularly the reduced occipital activity during expressive suppression, might be related to attenuated amygdala and visual cortex activation during emotion suppression tasks, as shown in multiple previous studies with adults and adolescents (Hayes et al., 2010; Hennenlotter et al., 2009; Stephanou et al., 2016; Wessing et al., 2015). However, this pattern of activity requires future interpretation in relation to the broader set of brain networks involved in both emotion generation and regulation. For example, although there have been very few fMRI studies of expressive suppression, meta-analytic reviews suggest that expressive suppression, relative to reappraisal and other strategies, engages inferior frontal gyrus and temporal-parietal junction regions (Morawetz et al., 2016). Thus expressive suppression may have some unique neural features relative to other emotion regulation strategies that are likely to involve more cognitive-semantic processes.

As far as the temporal features of emotion regulation are concerned, the findings of the present study seem to confirm that some forms of response modulation, specifically expressive suppression, need not always be deployed after the emotion is generated but may be deployed early as a preventative regulatory strategy. This is consistent with the findings of Paul et al. (2013) and Vanderhasselt et al. (2013), suggesting that preparatory or "preventative" expressive suppression can be used when the content of the stimulus cannot be anticipated and an effective reappraisal is not immediately possible.

Consistent with prior studies that indicated general age-related decreases of visual ERP amplitudes (Taylor et al., 2004; Kuefner et al., 2010; Sumich et al., 2012) and LPP-related occipital source activity (Wessing et al., 2015), the general pattern of the present study was also of overall decreasing ERP amplitudes, especially at occipital channels. Moreover, as predicted, the current study found evidence of developmental differences in the neural correlates of emotion-regulation. Specifically, we found negative associations between the LPP reductions in the emotion regulation condition and age across early to late adolescence (from 12 to 17 years). Overall the association with age is consistent with previous findings that reported neural correlates of emotion regulation change across development (McRae et al., 2012). More specifically, the results are consistent with findings from Kisley et al. (2007) showing that LPP to unpleasant images is reduced across the lifespan. The current findings suggest that this age-LPP association in part reflects a process of improved emotion regulation with maturation. This may indicate that the capacity to regulate becomes less effortful during the age span covered by this study, primarily due to normative psychological and neural maturation. In line with evidence that adults regulate emotions more efficiently than children (Pfeifer & Blakemore, 2012), our findings suggest that older adolescents, relative to younger adolescents, also have a greater capacity to regulate their emotions. However, because there was no direct measurement of subjective emotional changes, it is not possible to address the effectiveness of our protocol in reducing negative emotion felt by the participants.

Emotion regulation is a complex process with multiple components (Gross, 2015). Dan-Glauser and Gross (2011) describe an anticipatory autonomic/respiratory activity associated with expressive suppression in adults that occurs at the same time window (0–0.5 s) as the early parietal LPP increase during the expressive suppression condition in the present study. It is possible that this LPP increase is an EEG marker of the same preparatory "physiological suppression" process reported by Dan-Glauser and Gross (2011). While adults use emotion regulation strategies based on experience (Zimmerman & Iwanski, 2014) and with relatively low effort, adolescents may be less prepared, in terms of

learning and maturation, for the variety of emotionally evocative situations with which they are faced. Therefore the anticipatory activity involved with such physiological suppression is likely to demand more effort in adolescents compared to adults.

Zimmerman and Iwanski (2014) also showed that emotion regulation develops in an emotion specific manner, demonstrating an increased use of expressive suppression for fear from early adolescence to adulthood, but not for other emotions such as anger and sadness. Due to the nature of the IAPS images, which consist of some images that evoke fear, it is possible that the LPP decrease associated with age is linked to more habitual use of expressive suppression with increasing age in the current sample. It could be argued that the use of expressive suppression to deal with fear is adaptive, and the ability to use it improves with age. For example, concealing one's one fear may help in situations of danger (e.g., not showing fear to a threatening individual), whereas in other circumstances it may be part of acceptable social display rules (e.g., not showing personal fears in a group). However, the developmental pruning of personal emotion regulation strategies occurs in an idiosyncratic and context-dependent manner that is not yet well understood. Further, an additional possible explanation for the age related LPP reductions in both expressive suppression and negative view conditions may involve greater familiarity with extreme graphic media in the older adolescents.

More generally, it is interesting to consider the possible effects that may be unique to expressive suppression as a pre-emptive regulation strategy in adolescents as compared to antecedent-focused and response-modulation strategies. An individual may need to regulate the expression of emotions for a multitude of reasons such as: to comply to the social norms of a situation and adhere to display rules (not laughing at the teacher); to avoid others knowing what one actually feels (not showing a bully you are afraid); to help someone else to regulate his/her emotions (not showing one's anxiety to a younger sibling in a potentially dangerous situation). Broadly speaking, it is likely that the degree of adaptive expression of one's emotions varies greatly across different situations, relationships and cultures (Cole, Bruschi & Tamang, 2002; English et al., 2016; Yeh, Bedford, Wu, Wang & Yen, 2017).

Given the importance of peer relations in adolescence (Collins & Laursen, 2004), one's expressive behavior may often be under significant social scrutiny by peers, hence not showing one's emotions may often be an adaptive behavior. As adult studies have found that social context is relevant to expressive suppression (English et al., 2016) and enhancement (Burton & Bonanno, 2016), it is possible that the association between expressive suppression and age in the current study is driven by the fact that younger adolescents are less experienced in hiding their expressive behaviors as they are relatively "new" to the peer-focused context, while older adolescents may be significantly more practiced in it. This idea of practice and maturation effects due to social context is also in line with the hypothesis that suppression of fear may become more adaptive with increasing age, autonomy and responsibility (Zimmerman & Iwanski, 2014). One might also suggest that younger adolescents' relative lack of experience means there are more situations and emotions which would be novel and highly arousing to them. Hence pre-emptive, context-independent and generalized emotion regulation strategies would be used more frequently and generally be more beneficial for this age group. Hence suppression can operate by targeting emotional responses early, prior to a fully expressed emotional response. Adolescents may frequently use expressive suppression as it seems to be an effective strategy of emotion regulation when faced with uncertainty. The findings of the present study seem to support the view that expressive suppression in adolescents can successfully modify emotions relatively early during emotion generation and regulation processes.

4.1. Limitations and possibilities for future research

Several limitations should be considered when interpreting the current findings. First, the images we used were not classified according to specific emotion categories (e.g., fear, disgust), but into broad neutral and negative emotional categories. Therefore, it is difficult to reach conclusions about any emotion-specificity in the effects of expressive suppression on the LPP. This is a significant limitation as emotion regulation may develop in an emotion-specific manner (Zimmerman & Iwanski, 2014). Second, we did not collect self-report emotion ratings and were not able to assess the effectiveness of expressive suppression in reducing the intensity of negative emotions felt. Third, the images were somewhat smaller than in past paradigms, thus the total emotional impact of the images on participants may have been somewhat diminished. Fourth, we did not control for social anxiety that may have been brought about due to being watched on video by the researcher while suppressing. Fifth, only one emotion regulation strategy was explored as part of this study, not allowing for comparisons between various emotion strategies, or their differential associations with age. It is important that future studies explore and compare multiple regulation strategies across a range of emotions. Sixth, the analyses were limited by being focused on a few single channels, and by being cross-sectional for age analyses.

In line with previous studies mentioned in the methods section, this study did not use a counterbalanced experimental design in order to avoid potential carryover effects of doing expressive suppression before the passive view conditions, thus likely maximizing the suppression challenge. However this experimental design results in a frequently reported tradeoff of not being able to be sure that the study effects were due to the possible differences between conditions and, specifically, their sequential effects on each other. The effects we have reported could be driven by or confounded with several factors including condition order, priming, habituation, cognitive load, and fatigue; and not due to the expressive suppression instructions per se. We attempted to minimize possible habituation effects between the passive viewing and expressive suppression blocks by using unique negative stimuli of similar intensity across the two conditions. Relatedly, Murata et al. (2012) pointed out that habituation effects should be minimal due to the robust LPP reactivity with repeated presentations of IAPS images (see Olofsson et al., 2008 for review). Further, the two conditions differed in the way the instructions were presented, thus the reported study effects in the expressive suppression condition relative to passive viewing conditions may have also been influenced by the pre-trial audiovisual cue. Overall, while our findings should be taken with caution until replication and extension, the general pattern of ERP findings reported here matches well with published results using similar emotion regulation instructions. Thus it is our view that the main ERP effects related to expressive suppression were at least partly influenced by the expressive suppression instructions. In future studies the limitations related to counterbalancing could be addressed through arranging two separate visits for the participants as well as introducing ratings of stimulus intensity and cognitive effort.

As the parameters of expressive suppression tasks are not well studied, particularly with EEG and pediatric samples, the present study was designed to encourage an explicit use of expressive suppression and reminded the participant to use this regulation technique before each trial. However this reminder was delivered in a form of an audio-visual cue which was not present in the passive viewing conditions, therefore it is possible that the results of the study were partially influenced by this difference between the two conditions. We believe that if there are confounding effects from pre-trial cues, they most likely influenced early aspects of the trials and not the main LPP effects. Further, the pre-trial cue was early enough before the onset of the stimulus (2500 ms) to probably minimize pre-trial cue effects on the ERPs in this study.

An additional last limitation is related to the age range of participants in this study. We focused on the age range between 12 and 17; however, there is evidence of brain development associated with emotion regulation continues well into the 20's and may be modified throughout the lifespan (Blakemore & Choudhury, 2006). In order to

further our understanding of change in emotion regulation associated with development, future studies should explore the neural correlates of emotion regulation strategies across broader age spans, or indeed, the entire life span.

5. Conclusion

The present study is the first to examine the ERP correlates of expressive suppression in an adolescent sample. This study had successfully replicated and extended previous adult findings by demonstrating that the LPP is sensitive to emotion regulation instructions in an adolescent population. The main findings were 1) age-related LPP decreases suggestive of greater facility with expressive suppression in older adolescents, which is likely due to normative developmental changes in emotion regulation networks; 2) an occipitally-focused LPP, not reported in adults but previously found in child studies, and 3) early, middle, and late window LPP effects due to expressive suppression. Further, both LPP increases and decreases were noted, depending on electrode site and time window. More broadly speaking, the current findings support the idea that expressive suppression is effective in significantly modulating the neural correlates of emotion regulation in adolescents. The decreased LPP with increasing age in our study may serve as a useful metric of normative brain and emotion regulation maturation. With continued exploration of the experimental constraints on the LPP and individual-difference variations in the LPP, it may come to serve as clinically relevant marker to index emotion-regulation processes in normally developing adolescents and those at risk for psychopathology.

Acknowledgment

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