Chapter 13

Event-Related Potentials and Emotion Dysregulation

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Abstract

Emotion dysregulation is a common feature of many psychological disorders. To date, however most research evaluating emotion regulation has been limited to self-report assessments. Event-related potentials (ERPs) are well suited to disentangle discrete aspects of emotional processing that are critical to understanding both healthy and aberrant emotional functioning. In this chapter, we focus on a particular ERP component, the late positive potential (LPP), and review evidence that the LPP is modulated by emotional content and is sensitive to various emotion regulation strategies. Next, studies leveraging the LPP to examine individual differences in emotional processing in the context of psychopathology are reviewed. Finally, we discuss methodological limitations of past research and current gaps in our understanding, including suggestions for future research using ERPs to study emotion dysregulation.

Keywords: Event-Related Potential, Late Positive Potential, Emotion, Regulation, Depression, Anxiety, Trauma, Substance Use

Introduction

There are many ways to conceptualize emotion and emotion regulation. In this chapter we consider emotions as transient changes in one's subjective experience, behavior, and physiology that result from motivationally salient internal or external cues (Gross, 2015; Lang, 1995). In turn, emotion regulation reflects the initiation of a goal to modify one's experiential, behavior, and/or physiological emotional response tendencies in order to facilitate adaptive behavior (Gross, 1998; Gross, Sheppes, & Urry, 2011; Thompson, 1990). Therefore, emotion *dysregulation* can be conceptualized as any pattern of emotional experience and/or expression that interferes with appropriate goal-directed behavior (Beauchaine, 2012; Beauchaine, Gatzke-Kopp, & Mead, 2007). This definition of emotion dysregulation includes abnormalities at any stage in processes of emotion generation, including reactivity, and/or subsequent regulation. We therefore review work that addresses each of these processes. Emotion dysregulation has been described as a transdiagnostic factor of psychopathology (Fairholme et al., 2013; Kring & Sloan, 2009), as most psychiatric disorders involve the experience of emotions that are too intense or too prolonged to be adaptive (Beauchaine, 2012; Beauchaine et al., 2007).

Most early research on emotion and emotion regulation relied on subjective reports of emotional experience (Clore, 1994; Diener 2000; Watson, 2000), since self-report measures are convenient and not limited to assessment of current emotions. However, as reflected in broader conceptualizations of emotion, subjective experience is only one part of the multifaceted processes outlined above. Moreover, evidence demonstrates that when individuals report on their current experiences of emotion versus their past, future or 'typical' emotional experiences, they tend to use different sources of information (e.g., experiential information versus generalized beliefs), resulting in important discrepancies across different types of self-reports (Robinson &

Clore, 2002). Thus, it is necessary to use multimethod assessments that leverage different dependent measures to more comprehensively assess emotional processes and their regulation.

Meaningful changes in emotional processing occur rapidly, and electrocortical measures derived from event-related potentials (ERPs) are an ideal method for studying neural correlates of emotional processing (Weinberg, Ferri, & Hajcak, 2013). ERPs represent near instantaneous event-locked activity of large and synchronous neural populations—which is ideal for quantifying rapid changes in brain activity. In fact, ERPs can be used to track neural changes in response to emotional stimuli on a millisecond-by-millisecond basis, making it possible to effectively isolate and quantify core aspects of emotion reactivity and emotion regulation. Furthermore, compared to other neuroimaging techniques, ERPs are relatively inexpensive, have few contra-indications, and are well-tolerated in both young and old populations.

Several distinct ERPs are modulated by emotional stimuli, such as the P200 and the P300 (Carretie, Hinojosa, Martin-Loeches, Mercado, & Tapia, 2004; Crowley & Colrain, 2004; Huang & Luo, 2006; Lifshitz, 1966; Mini et al., 1996; Naumann, Bartussek, Diedrich, & Laufer, 1992; Schupp, Junghöfer, Weike, & Hamm, 2004). Although these ERPs appear to index early attention to salient information, they are not well suited to capture changes in emotional responses that result from emotion regulation. Accordingly, we focus on the late positive potential (LPP), which can be used to assess both emotional processing as it unfolds over time, emotion regulatory processes. Although the LPP has been used to study individual differences across various psychiatric disorders, we focus on the most commonly examined disorders, including depression, anxiety, substance abuse/dependence, and post-traumatic stress disorder.

The Late Positive Potential: From Emotional Reactivity to Regulation

The LPP is a positive deflection maximal at central-parietal midline recording sites that begins by 200 ms after stimulus onset (Foti, Hajcak, & Dien, 2009). As depicted in Figure 1, the

LPP is potentiated by emotional (e.g., pleasant, unpleasant) compared to neutral stimuli, and the LPP magnitude remains potentiated for the duration of stimulus presentation (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Hajcak & Olvet, 2008; Hajcak, Weinberg, MacNamara, & Foti, 2011). Unlike many other psychophysiological measures (Breiter et al., 1996; Codispoti & De Cesarei, 2007; Codispoti, Ferrari, & Bradley, 2006, 2007), potentiation of LPPs to emotional relative to neutral stimuli does not habituate over repeated presentations (Codispoti et al., 2006; Levinson, Speed & Hajcak, in prep). It has been proposed that the LPP indexes sustained attention and engagement with emotional content (Hajcak, MacNamara, & Olvet, 2010; Hajcak & Olvet, 2008; Hajcak et al., 2011; Weinberg & Hajcak, 2011b).

A variety of motivationally salient stimuli elicit LPPs, such as emotional scenes, faces, and words (Cuthbert et al., 2000; Dillon, Cooper, Grent-‘t-Jong, Woldorff, & LarBar, 2006; Eimer & Holmes, 2007; Schupp, Cuthbert, et al., 2004; Speed, Levinson, Gross, Kiosses, & Hajcak, 2017). In addition, emotional modulation of LPPs appear to be independent of perceptual features of stimuli, including size (De Cesarei & Codispoti, 2006), and other perceptual characteristics (Bradley, Hamby, Low, & Lang, 2007). Previous work indicates that emotional modulation of LPPs reflects emotional intensity of stimulus content, and is not due merely to stimulus novelty, perceptual differences, or expectation violations. Emotional modulation of the LPP is subject to genetic influence (Weinberg, Venables, Proudfit, & Patrick, 2015), and thus, magnitude differences in LPPs may specify a heritable biomarker of individual differences in emotional processing. It is important to note that psychometric evaluations of LPPs to emotional scenes and adjectives indicate good test-retest reliability and internal consistency, supporting its appropriateness for the study of individual differences in emotional processing (Auerbach, Bondy et al., 2016; Codispoti et al., 2006; Moran, Jendrusina, & Moser, 2013).

Unlike many more transient ERPs, emotional modulation of LPPs is sustained throughout stimulus presentation (i.e., for several seconds; see Hajcak et al., 2010), and can be observed for as long as 1000 ms after stimulus offset (Hajcak & Olvet, 2008). The time-course of LPPs supports the argument that emotional content not only captures, but also holds attention (Vuilleumier, 2005). Spatially, LPPs appear to shift over the course of emotional processing, beginning with a parietally-maximal distribution that progresses to a centrally-maximal distribution. This ‘frontalization’ may suggests that earlier versus later segments of LPPs reflect separable components (Foti et al., 2009; Hajcak et al., 2011; MacNamara et al., 2009). Indeed, earlier segments of the LPP (300-600ms) appear to represent more automatic processing of emotional content, whereas later segments (600ms and beyond) may represent more deliberative engagement with stimulus content (Olofsson, Nordin, Sequeira, & Polich, 2008; Weinberg & Hajcak, 2011b; Weinberg, Hilgard, Bartholow, & Hajcak, 2012). Previous research demonstrates that the duration of LPPs can be manipulated using instructions that encourage participants to maintain previously viewed stimuli in working memory, supporting the argument that more sustained aspects of LPPs index intentional engagement with emotional stimuli (Hajcak et al., 2010; Thiruchselvam, Hajcak, & Gross, 2012).

Critically, LPPs are sensitive to various emotion regulation strategies, making them ideal for studying individual differences in emotion regulation (Foti & Hajcak, 2008; Hajcak & Nieuwenhuis, 2006; Krompinger, Moser, & Simons, 2008; Moser, Hajcak, Bukay, & Simons, 2006; Thiruchselvam, Blechert, Sheppes, Rydstrom, & Gross, 2011). For example, studies that use open-ended (i.e., non-specific) instructions to reduce the intensity of negative emotions show that LPPs to unpleasant pictures are attenuated during regulation relative to control conditions (Krompinger et al., 2008; Moser et al., 2006). In an evaluation of effects of cognitive reappraisal on LPPs, Hajcak and Nieuwenhuis (2006) demonstrated that LPP magnitude was substantially reduced when participants were instructed to reinterpret unpleasant pictures using cognitive reappraisal relative to when participants were instructed to simply attend to unpleasant picture content (see Figure 2). Furthermore, reduction in LPP amplitude during reappraisal was correlated positively with reductions in self-reported emotional intensity following reappraisal. Parvaz and colleagues (2012) found similarly that LPPs in response to unpleasant pictures were reduced following instructions to use cognitive reappraisal compared to unpleasant pictures that were viewed normally. This effect appears to be independent of methodological differences across studies, such as how (visual versus auditory) and when (before versus after picture onset) reappraisal instructions are provided (Hajcak & Nieuwenhuis, 2006; Parvaz, MacNamara, Goldstein, & Hajcak, 2012). For instance, one study provided auditory reappraisal frames before picture viewing (i.e., "preappraisal"), and found that LPPs were reduced in response to unpleasant pictures that followed neutral descriptions, compared to LPPs elicited by unpleasant pictures that followed negative descriptions (Foti & Hajcak, 2008). Replicating and extending these findings, MacNamara and colleagues (2009) found that LPPs were potentiated when neutral pictures were preappraised in negative terms, demonstrating that effects of appraisal on LPPs are not specific to unpleasant pictures. Furthermore, cognitive reappraisal attenuates LPPs when participants view words linked to negative autobiographical memories (Speed et al., in press). This suggests that cognitive reappraisal is an effective strategy in reducing LPPs elicited by idiographic stimuli. Together, these findings illustrate that changing the meaning of an emotional stimulus, via reappraisal or preappraisal, can alter amplitudes of LPPs.

In addition to cognitive reappraisal, manipulations of visual attention can effectively modulate LPPs. For example, when pictures of neutral or fearful faces were presented in attended locations during a spatial attention task, participants demonstrated a potentiated LPP to fearful relative to neutral faces (Holmes, Vuilleumier, & Eimer, 2003). However, the effect of emotion expression on LPPs was eliminated when faces were presented in unattended locations.

Extending these findings, Eimer, Holmes and McGlone (2003) found that LPPs are potentiated to faces displaying six basic emotions (angry, disgusted, fearful, happy, sad, and surprised) relative to neutral, but only when faces are the focus of direct attention (see also Keil, Moratti, Sabatinelli, Bradley, & Lang, 2005). These findings are potentially important, since shifting spatial attention is a relatively common and effective strategy for regulating emotion. For example, when instructed to decrease emotions to unpleasant images, participants frequently look at unimportant or non-emotional areas of pictures—and such changes in gaze account for significant variance in brain activity as assessed by fMRI (van Reekum et al., 2007). Similarly, LPP magnitude is reduced when participants' gaze is directed to low arousal aspects of unpleasant pictures compared to when their gaze is directed to high arousal parts of pictures (Dunning & Hajcak, 2009; Hajcak, Dunning, & Foti, 2009). Thus, volitional redirection of spatial attention appears to be an effective strategy for altering LPP magnitude during processing of visual emotional information. These findings suggest that altering the meaning of or modifying attention to an emotional stimulus can modify the magnitude of LPPs.

Emotional modulation of LPPs can be observed in children as young as 5 years (Hajcak & Dennis, 2009), making it possible to study developmental changes in emotional processing over the lifespan. Evaluations of developmental differences reveal that younger (18-26 years) and older (60-77 years) adults display comparable modulation of LPPs when viewing emotional compared to neutral pictures, and comparable regulation of LPPs to emotional pictures (Langeslag & Van Strien, 2010). Notably, childhood and adolescence are characterized by considerable reorientation in affective processing and changes in cognitive control (Nelson, Leibenluft, McClure, & Pine, 2005; Luna, Padmanabhan, & O'Hearn, 2010), raising questions about when specific emotion regulation skills are acquired, and trajectories of their functioning. Data suggest that older children (8-10 years) can effectively use directed reappraisal to reduce

LPP amplitude to unpleasant pictures (DeCicco, O'Toole, & Dennis, 2014; Dennis & Hajcak, 2009). However, young children (5-7 years) do not display reduced LPPs to unpleasant pictures using directed reappraisal (Babkirk, Rios, & Dennis, 2015; DeCicco et al., 2014; Dennis & Hajcak, 2009). Thus, this cognitive ability may not emerge until ages 8-9, though within-subjects comparisons are needed before strong conclusions are drawn. Babkirk and colleagues (2015) evaluated individual differences in emotion regulation ability among children ages 5-10 years by comparing those who displayed reappraisal-induced reductions in LPPs to those who did not, and found that children who showed reductions in the LPP using reappraisal displayed more adaptive emotion regulation strategies both concurrently and two years later. These data provide support for the LPP as a useful index of emotion regulatory capacity in children, which may help in early-identification of those at increased risk for development of emotional problems.

Emotion Dysregulation in Psychopathology: Evidence from the LPP

Depression

Major depressive disorder (MDD) is characterized by pronounced feelings of sadness, and/or loss of pleasure in previously enjoyed activities (American Psychiatric Association, 2013). Oftentimes, MDD involves a combination of increased negative affectivity (e.g., irritability) and decreased positive affectivity (e.g., anhedonia). Consequently, it stands to reason that depressed individuals should demonstrate increased reactivity to mood congruent negative stimuli and decreased reactivity to mood incongruent positive stimuli. To some extent, this is consistent with data derived from depressed individuals when they evaluate the personal relevance of verbally presented word stimuli.

The self-referential encoding task (SRET; Rogers, Kuiper, & Kirker, 1977) has been used to investigate depressogenic self-referential biases in depression. In this task, participants are asked to make judgements regarding whether positive (e.g., happy, excited) or negative (e.g., loser, worthless) adjectives are self-descriptive. Past reveals that depressed adults and adolescents demonstrate potentiated LPPs to negative relative to positive adjectives during the SRET, whereas non-depressed individuals display potentiated LPPs to positive relative to negative adjectives (Auerbach, Stanton, Proudfit, & Pizzagali, 2015; Shestyuk & Deldin, 2010). Thus, depressed adolescents and adults exhibit abnormal neural responses to negative compared to positive stimuli in the SRET. Furthermore, never-depressed children and adolescents who are at elevated risk for depression based on maternal life history of MDD also display potentiated LPPs to negative words during the SRET—an effect that is independent of current depressive symptoms (Speed, Nelson, Auerbach, Klein & Hajcak, 2016). Increased risk for depression is therefore associated with more elaborative processing of negative information, which may be important for the development of negative schemas and reflect vulnerability for depression.

Although depressed individuals and those who are at risk exhibit increased LPPs to negative relative to positive words, studies that use standardized emotional picture sets typically find that LPPs are *attenuated* in response to both pleasant and unpleasant stimuli among depressed individuals (for a review see Proudfit, Bress, Foti, Kujawa, & Klein, 2015). Although this pattern of emotional responding appears to run counter to descriptions of depression, it is consistent with the Emotion Context-Insensitivity (ECI) model proposed by Rottenberg and colleagues (Rottenberg & Gotlib, 2004; Rottenberg, Gross, & Gotlib, 2005). According to this model, emotional dysfunction in MDD is best understood as lack of engagement with emotional stimuli in the environment. In an early study involving passive viewing of emotional words, individuals with MDD showed blunted LPPs to both pleasant and unpleasant emotional words, although the LPP to neutral words did not differ (Blackburn, Roxborough, Muir, Glabus, & Blackwood, 1990). In addition, Kayser and colleagues found that patients with MDD demonstrated blunted LPPs when viewing unpleasant pictures of dermatological disease (Kayser, Bruder, Tenke, Stewart, & Quitkin, 2000). Consistent with these early studies, a growing body of research suggests that both MDD and elevated depressive symptoms are associated with reduced LPPs to positive and negative emotional stimuli among both children and adults (Foti, Olvet, Klein, & Hajcak, 2010; Kujawa, MacNamara, Fitzgerald, Monk, & Phan, 2015; MacNamara, Kotov, & Hajcak, 2016; Weinberg, Perlman, Kotov, & Hajcak, 2016). Notably, blunted LPPs to emotional stimuli may be associated with a specific subgroup of depressed individuals who experience early onset depression. Weinberg and colleagues (2016) found that only patients with early onset depression (first episode before age 18 years) displayed reduced LPPs to positive and negative pictures, whereas individuals with adult-onset depression exhibited LPPs that were comparable to never-depressed controls. These findings were evident despite similar clinical presentations of symptoms across depressed groups at the time of the study, suggesting that variability in the LPP to emotional stimuli may reflect a specific phenotype of early onset depression.

Consistent with the notion that emotion context insensitivity is a risk factor for depression, blunted LPPs to emotional faces and scenes are observed in children of parents with lifetime histories of depression (Kujawa, Hajcak, Torpey, Kim, & Klein, 2012; Nelson, Perlman, Hajcak, Klein, & Kotov, 2015), and among adolescent girls with low positive emotionality—a personality trait associated with risk for depression (Speed et al., 2015). Furthermore, in a prospective study of girls ages 8-14 years at baseline, when controlling for initial depressive symptoms, blunted LPPs to emotional pictures interacted with increased negative life events to predict increases in depressive symptoms two-years later (Levinson, Speed, & Hajcak, 2017). Therefore, data from at-risk children and adolescents suggest that blunted LPPs to emotional stimuli may be a promising biomarker of vulnerability to depression following stress.

Taken together, evidence from SRET and passive viewing paradigms indicate that depressed and at-risk individuals experience aberrant emotional processing. However, there is a paucity of

ERP research investigating abnormalities in effortful (i.e., explicit) emotion regulation in depressed individuals. In a small community sample of children ages 5-10 years, anxious-depressed symptoms were associated positively with larger LPPs during directed reappraisal, suggesting that children with elevated internalizing symptoms are less able to regulate their reactions to unpleasant images (Dennis & Hajcak, 2009). Of note, engaging in effortful cognitive reappraisal can affect subsequent responding on experimental tasks (Dillon et al., 2007; Richards & Gross, 2000; Richards, Butler, & Gross, 2003; Sheppes, Catran, & Meiran, 2009). For example, LPPs are potentiated on trials immediately following cognitive reappraisal, and magnitudes of LPPs following reappraisal are associated positively with depressive symptoms (Parvaz et al., 2015). This suggests that cognitive reappraisal may require greater engagement of top-down resources among depressed individuals.

Others have examined LPPs to evaluate individual differences in emotional reactivity and regulation associated with suicidality—a common and severe symptom of depression (and several other psychiatric disorders). Among a clinical sample of individuals with anxiety and/or unipolar depressive disorders and healthy controls, current severity of suicidal ideation was associated with blunted LPPs to both rewarding and threatening images across all participants, even when controlling for other symptoms of depression (Weinberg et al., 2016). These data may suggest that disengagement from emotional stimuli—as indexed by LPPs—may be linked to suicidality across diagnostic boundaries. Furthermore, regardless of current suicidal ideation, outpatients who have attempted suicide exhibit blunted LPPs to threatening pictures, but not rewarding or neutral pictures (Weinberg, May, Klonsky, Kotov, & Hajcak, in press). Thus, diminished reactivity to threat specifically may distinguish suicide attempters from ideators. Data also suggest that suicidal ideation is associated with abnormalities in using adaptive emotion regulation strategies, including cognitive reappraisal. For example, undergraduates with histories of suicidal ideation show larger LPPs to dysphoric images during cognitive reappraisal (Kudinova et al., 2016).

To summarize, depressed individuals display potentiated LPPs when viewing negative relative to positive adjectives during the SRET, indicating negative self-referential bias. In contrast, when viewing emotional pictures that are not self-referential, those with depression, and those with histories of suicidal ideation, show blunted LPPs to both negative and positive stimuli, reflecting disengagement from salient environmental information. Although few studies have used LPPs to examine abnormalities in effortful regulation in depression, there is some evidence that depressive symptoms and suicidal ideation are associated with larger LPPs during and following cognitive reappraisal, suggesting difficulties using cognitive reappraisal to reduce negative emotion. However, more research on effortful regulation is needed using clinically depressed and at-risk samples, ideally comparing more than one type of regulation strategy to more thoroughly evaluate the nature of emotion dysregulation in depression.

Anxiety

Depression and anxiety are often comorbid and share many features (Goldberg, Krueger, Andrews, & Hobbs, 2009). Nevertheless, evidence from LPP studies suggests that depression and anxiety differ somewhat in emotion dysregulation. In contrast to depression, anxiety is associated with *potentiated* LPPs to unpleasant pictures among both children and adults—an effect that may reflect heightened reactivity toward threat (Kuwaja et al., 2015; MacNamara et al., 2016; MacNamara & Hajcak, 2010). LPPs are potentiated to participant-specific fears, such as pictures of spiders in both adults and children with spider phobias (Kolassa, Musial, Mohr, Trippe, & Miltner, 2005; Leutgeb, Schäfer, Köchel, Scharmüller, & Schienle, 2010; Leutgeb, Schäfer, & Schienle, 2009; Michalowski et al., 2009; Miltner et al., 2005), pictures of faces in individuals with social anxiety (Moser, Huppert, Duval, & Simons, 2008; Mühlberger et al., 2009), disorder-relevant pictures in patients with obsessive-compulsive disorder (OCD; Paul, Simon, Endrass, & Kathmann, 2016), and aversive pictures in individuals with generalized anxiety disorder (GAD; MacNamara & Hajcak, 2010). In an outpatient sample, MacNamara and colleagues (2016) found that both diagnosises of and symptoms of GAD were associated with potentiated LPPs to unpleasant pictures, controlling for MDD diagnoses, whereas MDD was associated with blunted LPPs to unpleasant pictures. Consistent with studies among adults, adolescents with anxiety disorders exhibit potentiated LPPs to angry and fearful faces compared to healthy controls, an effect that is also modulated by depressive symptoms, such that higher depressive symptoms were associated with reduced LPPs to angry faces in both groups (Kujawa et al., 2015). Notably, potentiated LPPs to angry faces predicted better treatment response to both cognitive-behavior therapy (CBT) and anti-depressant medication, even accounting for pre-treatment anxiety severity (Bunford et al., 2016). Thus, increased LPPs to threatening images may be a useful biomarker for identifying individuals most likely to respond to treatment.

There is also evidence that individuals with phobias display an attentional pattern of early vigilance followed by avoidance to feared stimuli. Those with spider phobia exhibit potentiated LPPs to spider stimuli relative to other negative stimuli during an early time window (340-770ms), but not during a later time window (800-1500ms). This may reflect a maladaptive emotion regulation strategy (avoidance) that prevents habituation to feared stimuli (Leutgeb et al., 2009). Individuals who complete exposure therapy display potentiated and sustained LPPs to spider stimuli, consistent with the possibility that exposure therapy reduces avoidance (Leutgeb et al., 2009). This finding has been replicated in individuals with generalized anxiety disorder, who were characterized by a potentiated *early* neural response (P100) to unpleasant compared to neutral pictures, and an attenuated *later* LPP to unpleasant compared to neutral pictures relative to healthy controls. This supports the argument that anxious individuals experience early hypervigilance to threatening stimuli followed by failure to engage in elaborative processing (Weinberg & Hajcak, 2011a). In addition to using maladaptive emotion regulation strategies, some individuals with anxiety may experience difficulty using adaptive emotion regulation strategies, such as cognitive reappraisal. For instance, Paul and colleagues (2016) observed that in contrast to healthy controls, patients with OCD were unable to reduce the magnitude of their LPPs to unpleasant and disorder-relevant pictures using cognitive reappraisal—an effect that was associated with less frequent use of reappraisal in daily life.

Taken together, this research highlights the importance of assessing both anxious and depressive symptoms when examining individual differences in emotion dysregulation, as these frequently comorbid disorders may be characterized by differing patterns of reactivity to aversive stimuli. Moreover, individual differences in the time-course of the LPP might be leveraged to understand important changes in emotional processing that unfold over time, such as maladaptive vigilance-avoidance patterns, which could be targeted in treatment. Finally, much like research on depression, there is scant evidence regarding regulation deficits in anxiety using the LPP.

Post-Traumatic Stress Disorder

Emotion dysregulation is a core feature of PTSD (Etkin & Wager, 2007). Several symptoms of PTSD, including intrusive traumatic memories, avoidance of trauma-related cues, and abnormal reactivity (e.g., heightened arousal, emotional numbing; American Psychiatric Association, 2013), indicate that emotion dysfunction may occur at several different stages in emotional processing, and that significant heterogeneity in the type of emotion dysregulation may exist across individuals. Therefore, it is not entirely surprising that evidence regarding the nature of emotion dysfunction using the LPP is equivocal (for a review see Lobo et al., 2015). For example, when using a passive picture viewing paradigm in an undergraduate sample Lobo et al. (2014) found that greater symptoms were associated positively with LPPs to unpleasant relative to neutral pictures. Symptom severity therefore was associated with heightened reactivity to negative stimuli. Similarly, individuals with PTSD display potentiated LPPs when viewing trauma-specific questions relative to neutral questions (Wessa, Jatzko, & Flor, 2006). Combat-veterans with PTSD symptoms show potentiated early-window LPPs to trauma-related smells (e.g., diesel fuel), and increased LPP amplitudes to these scents are associated with greater reduction in symptoms following treatment (Bedwell et al., 2017). Thus, PTSD is associated with heightened LPP reactivity to trauma-related cues, and emotional modulation of LPPs might serve as a treatment response moderator. However, more research is needed using larger, more representative samples. In addition, Fitzgerald et al. (under review) found that potentiated LPPs to negative relative to neutral pictures during a baseline assessment predicted elevated re-experiencing symptoms over the next year. Thus, individual differences in emotional reactivity may relate to changes in specific symptoms over time. Notably, there is some evidence that individual differences in emotional processing prior to trauma may predict who is most likely to experience symptoms. For example, among children exposed to a natural disaster, potentiated LPPs to negative images—assessed prior to the disaster—prospectively predicted psychiatric symptom severity in the six months following the disaster (Kujawa et al., 2016).

In contrast, other studies using emotional picture viewing paradigms have failed to find differences in LPPs between combat-veterans with and without PTSD (Fitzgerald et al., 2016; Wessa, Karl, Flor, 2005; Woodward et al., 2015). Some studies using an emotional face-matching paradigm in combat-exposed veterans found that veterans with PTSD displayed smaller LPPs to angry faces relative to veterans without PTSD (DiGangi et al., 2017; MacNamara, Post, Kennedy, Rabinak, & Phan, 2013). In addition, MacNamara et al. (2013) found that LPPs in response to fearful faces were associated negatively with intrusive (re-experiencing) symptoms. Blunted processing of negative emotional faces, possibly due to numbing or avoidance, may therefore be linked to both diagnoses and specific symptom dimensions of PTSD (e.g., re-experiencing).

Extending beyond reactivity, Fitzgerald et al. (2016), using a cross-sectional design comparing emotion regulation ability in combat veterans with and without PTSD, found no group differences in LPPs before or during cognitive reappraisal to negative pictures. Rather, reappraisal resulted in similar reductions of LPPs in both veterans with and without PTSD. In contrast, smaller reductions in LPPs during reappraisal to negative images, relative to when viewing negative images, were associated with greater PTSD symptoms one year later among combat-exposed veterans—even controlling for baseline PTSD, depression, and anxiety symptoms (Fitzgerald et al., under review). Thus, although individuals with PTSD may not experience difficulties using cognitive reappraisal to decrease negative emotion compared to individuals without PTSD, difficulties in down-regulating negative emotion may be a useful predictor of symptom change among combat-exposed veterans.

In sum, variation in LPP effects across studies supports the notion that PTSD is a heterogeneous disorder. Individuals with PTSD vary greatly in their experience of emotion dysregulation (e.g., blunted reactivity, heightened reactivity, reappraisal deficits), and important changes in specific symptoms may occur within individuals over time. Inconsistent findings may be partially due to methodological differences, including task and stimuli used to elicit LPPs, timing of assessments (cross-sectional versus longitudinal), and differences in types of symptoms examined (e.g., clinical diagnoses, overall symptom severity, specific symptom severity). Therefore, whether individuals with PTSD demonstrate elevated or reduced emotional reactivity and regulatory abilities may depend on the type of emotional stimuli used to elicit the LPP, and the relative role of specific symptom dimensions.

Substance Abuse and Dependence

For most substances, neurobiological models of addiction are based on the notion that drugs co-opt then modify reward processing by increasing the motivational salience of drug-related cues and by reducing the motivational salience of non-drug-related cues (Koob & Volkow, 2010; Volkow, Koob, & McLellan, 2016). Because LPPs are thought to reflect increased processing of motivationally salient stimuli (see above), it is unsurprising that several studies have examined abnormalities in LPPs to drug-related stimuli among individuals with substance use disorders (SUDs). Evidence from early studies suggests that drug-related pictures elicit larger LPPs compared to neutral pictures in individuals with alcohol (Namkoong, Lee, Lee, Lee, & An, 2004), cannabis (Nickerson et al., 2011), cocaine (Dunning et al., 2011; Franken, Hulstijn, Stam, Hendriks, & van den Brink, 2004; Franken et al., 2008; van de Laar, Licht, Franken, & Hendricks, 2004) and heroin (Franken, Stam, Hendriks, & van den Brink, 2003; Yang, Zhang, & Zhao, 2015) use disorders. Thus, these individuals show increased sustained attention to addiction-related stimuli. Furthermore, increased LPPs to cocaine pictures are associated with cocaine craving (Franken et al., 2003).

Extending these findings, studies show that individuals with opiate use disorder display increased LLP responding to drug-related stimuli and decreased responding to non-drug-related (i.e., pleasant) stimuli compared to controls (Lubman, Allen, Peters, & Deakin, 2008; Lubman et al., 2009). Similarly, individuals with cocaine use disorders display potentiated early LPPs to cocaine-related pictures relative to controls, and blunted LPPs to standardized pleasant and unpleasant pictures (Dunning et al., 2011). Evidence suggests that smokers who display potentiated LPPs to cigarette-related cues compared to pleasant pictures are less likely to achieve long-term (6 months) smoking abstinence following intervention, compared to smokers who display potentiated LPPs to pleasant pictures relative to cigarette-related cues (Versace et al., 2012). Therefore, individual differences in sensitivity to reward-related cues, as indexed by the LPP, may be useful in predicting long-term outcomes (for a review see Moeller & Paulus, 2017).

Indeed, studies of individuals with substance use disorders show blunted LPPs to normative pleasant stimuli predict future relapse and drug use (Lubman et al., 2009; Versace et al., 2017; Versace et al., 2012). Thus, blunted responding to naturally rewarding stimuli may be a vulnerability to continued use. There are also data indicating that abstinence reverses magnitude differences in LPPs between drug-related and pleasant stimuli in treatment-seeking individuals with cocaine-use disorder (Parvaz et al., 2017). Taken together, it appears that individual differences in LPPs to drug vs. emotional stimuli may indicate clinical progress. However, it remains unclear if findings generalize across different types of substances. In addition, consistent with studies that find cognitive regulation strategies can reduce drug craving (Kober, Kross, Mischel, Hart, & Ochsner, 2010), cognitive reappraisal and distraction reduce the magnitude of LPPs to smoking cues among both light and heavy smokers (Littel & Franken, 2011). Thus, effective regulation of craving associated cues is marked by LPP responses among individuals with differing levels of dependency.

In sum, studies of LPPs are consistent with models of drug addiction, which specify potentiated processing of drug-related stimuli at the expense of non-drug related motivationally-salient reinforcers (Koob & Volkow, 2010; Volkow et al., 2016). As with work in depression and anxiety, there remains limited understanding as to whether individuals with SUDs exhibit abnormalities in explicit emotion regulation as indexed by the LPP, as the majority of studies have only examined reactivity.

Summary and Future Directions

The LPP is a sustained positive deflection in the stimulus-locked ERP in response to emotional compared to neutral stimuli. Modulation of the LPP reflects motivational salience of stimulus content, which is subject to modification using various emotion regulation strategies. Given its unique ability to differentiate between various stages of emotional processing that occur over relatively short periods of time, the LPP is ideally-suited to examine individual differences in emotional reactivity and regulation associated with psychopathology and various forms of emotion dysregulation. Indeed, emotional processing abnormalities during emotional picture viewing are observed using LPPs across depression, anxiety, PTSD, and SUDs. Collectively, these data suggest that the LPP could be leveraged further as a transdiagnostic biomarker of emotion dysregulation.

Studies of individual differences have, by and large, examined emotional reactivity rather than emotion regulation. This imbalance indicates an important opportunity for future research to examine both processes in tandem. Emotion dysregulation is an important feature of many psychological problems, including eating disorders, personality disorders, and behavioral disturbances in children (just to name a few). However, few objective examinations of emotional processing using the LPP have been conducted in these populations, despite significant opportunities. For example, individuals with anorexia nervosa display increased LPPs to extremely underweight bodies relative to other body types, suggesting abnormalities in motivated attention toward body shapes (Horndasch et al., 2017). In addition, although emotion dysregulation is a hallmark of borderline personality disorder (BPD; Conklin, Bradley, & Westen, 2006; Glenn & Klonsky, 2009) studies examining emotional processing abnormalities in BPD using the LPP are rare. One study investigated negative bias in BPD using a forced-choice facial expression recognition task and found that patients demonstrated blunted early responding (P300) to predominantly happy faces, but not predominantly angry faces (Hidalgo et al., 2016). In addition, ERP evidence obtained during the SRET indicates that female youth with BPD show negative self-referential bias, as indexed by a potentiated LPPs to negative relative to positive adjectives (Auerbach, Tarlow, et al., 2016). Thus, adolescents with BPD allocate greater resources when processing negative self-referential information, similar to individuals with depression. To date, however, no studies have used the LPP to evaluate emotion regulation abilities among those with BPD. Linehan's (1993) biosocial theory argues that individuals with BPD display abnormalities at several stages of processing, including heightened reactivity, greater emotional intensity, and slow return to baseline, yet these aspects of the disorder are difficult to disentangle using traditional self-report, behavioral, or fMRI measures. Future research on BPD might use LPPs to evaluate aspects of emotion dysfunction proposed by Linehan, and elaborated and extended by she and her colleagues (Crowell, Beauchaine, & Linehan, 2009).

It is well established that quantifying the *magnitude* of LPPs is useful for evaluating individual differences in emotional reactivity and emotion regulation. However, there are other potentially valuable ways in which LPPs might be used to study emotion regulation (Tracy, Klonsky, & Proudfit, 2014). Similar to Linehan (1993), Davidson (1998) described several metrics for quantifying emotional responding in terms of *affective chronometry*. For example, the time it takes for an emotional response to reach its maximum may vary in important ways between individuals, and Davidson refers to this metric as *rise time to peak*. Correspondingly, *recovery time* is a metric that refers to the time it takes to return from the maximum response to baseline. In addition, the amount of time that responding remains above a threshold, or the *duration of response*, is an important component of affective chronometry that can be evaluated using the LPP. Although few studies have used Davidson's metrics to evaluate affective chronometry using the LPP, data suggest that the time-course of LPPs prompted by emotional stimuli can be modified by cognitive instructions (Hajcak & Olvet, 2008; Hajcak et al., 2010). Therefore, in addition to examining LPP magnitude, future studies might benefit from evaluating the time-course of LPPs to differentiate specific aspects of emotional processing that might be abnormal in various forms of psychopathology.

A general limitation of emotion regulation studies using ERPs is that they have relied on standardized emotional words, picture sets, and films (Buhle et al., 2014; Dillon et al., 2006; Gross, 2002; Hajcak, et al., 2010; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). Appraisal theories suggest that self-relevance of stimuli affects the intensity of resulting emotions, which in turn influence the success of regulation attempts (Ellsworth & Scherer, 2003). Thus, although there is strong evidence that adults can use cognitive reappraisal successfully to alter emotional responding to standardized emotional stimuli, and that responding to such stimuli has important associations with psychopathology, there may be important differences in one's initial reactivity and ability to use various emotion regulation strategies to self-relevant versus standardized stimuli. For example, investigations on emotional processing in depression find differential modulation of the LPP depending on whether emotional pictures or self-descriptive adjectives are used (e.g. see Foti et al., 2010; Shestyuk & Deldin, 2010). Using a novel word-viewing ERP paradigm, we recently asked participants to identify neutral and emotionally-charged autobiographical memories and generate keywords unique to each memory (Speed et al., in press). Consistent with studies using standardized stimuli, the LPP was potentiated when viewing words linked to negative compared to neutral memories. In addition, LPPs elicited by words related to negative memories were reduced following cognitive reappraisal compared to normal reactivity, demonstrating that the LPP can assess successful-down regulation of neural activity using idiographic stimuli. Consistent with the notion that idiographic stimuli are more salient than other stimuli, effect sizes following cognitive reappraisal were smaller than traditional studies using standardized stimuli. However, internal consistency of the LPP to negative idiographic words during emotion regulation was poor. Future studies are needed to further evaluate and optimize psychometric properties of LPPs in emotion regulation paradigms, particularly when using idiographic stimuli—assuming the goal is to examine individual differences (Hajcak, Meyer, & Kotov, 2017). Furthermore, within-participant studies using different types of stimuli and different modalities (see Brown & Cavanagh, 2017) are needed to determine how the nature of emotional stimuli (standardized vs. idiographic; visual versus auditory) affect healthy, disordered, and at-risk individuals.

Most of the research reviewed above examined emotion dysregulation in psychopathology using passive viewing paradigms, which provides important information regarding individual differences in motivated attention and emotional reactivity. Studies that have examined emotion regulation abilities have typically focused on individual differences in cognitive reappraisal or distraction—or have allowed participants to determine their own strategy. Although these studies provide important information on effects of regulation strategies on LPPs in general, the type of emotion regulation strategy used may affect neural responding differently, and different strategies may have distinct long-term consequences. For example, Thiruchselvam and colleagues (2011) found that distraction resulted in faster reduction of LPP magnitude compared to cognitive reappraisal; however, upon re-exposure to the negative stimuli, distraction history was associated with a larger LPP compared to cognitive reappraisal, suggesting that distraction had different shorter- versus longer-term effects on the LPP. One could imagine that this difference varies across individuals. To further elucidate these important differences and better understand the nature of emotion dysregulation in psychopathology, future research is required to compare effects of different types of emotion regulation strategies on the LPP, and to evaluate how such differences are associated with real-world emotional functioning and psychopathology.

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Figure 1. Top: Grand averaged ERP waveforms at electrode site CPz elicited during passive viewing of pleasant, neutral, and unpleasant pictures. Picture onset occurred at 0 msec. Negative voltage changes are plotted as upward deflections. Bottom: Voltage maps for pleasant minus neutral and unpleasant minus neutral comparisons at *t* = 700 msec. The figure is based on data collected by Hajcak and Nieuwenhuis (2006).

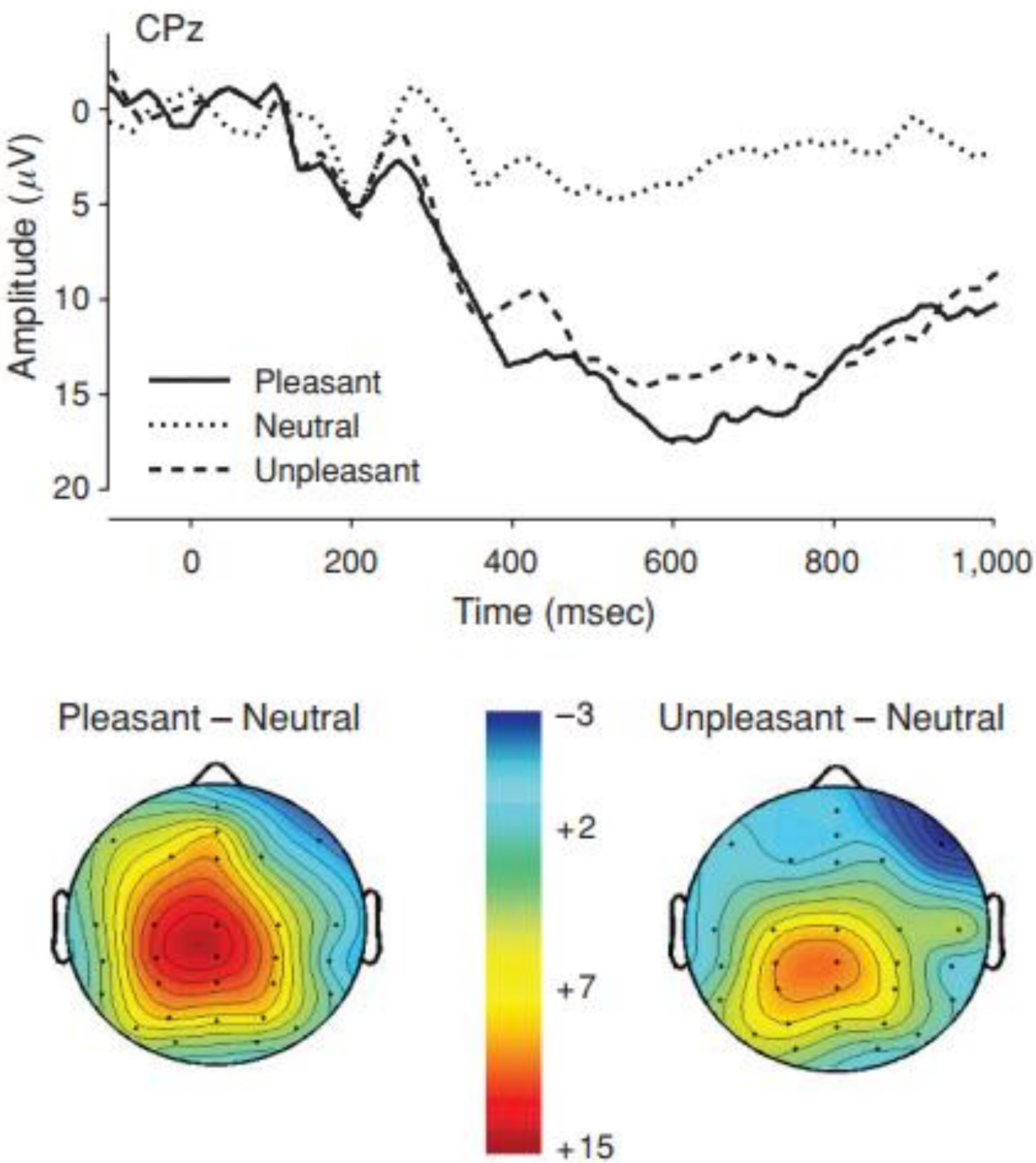

Figure 2. Left: Grand averaged ERP waveforms at electrode site CPz associated with unpleasant pictures during cognitive reappraisal (solid line) and focused attention (dashed line). Picture onset occurred at 0 msec. Negative voltage changes are plotted as upward deflections. Shaded gray areas represent 100-msec windows in which the reappraise LPP differed reliably from the attend LPP. Right: Voltage map for the attend minus reappraise comparison at *t* = 700 msec. The figure is based on data collected by Hajcak and Nieuwenhuis (2006).