ABSTRACT

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The current study investigated the neurophysiological underpinnings of emotional maintenance in schizophrenia (SCZ) and whether aberrant neural responses predicted deficits in affective decision making and real-world motivated behavior. Event-related potentials (ERPs) were recorded from 27 SCZ outpatients and 23 healthy controls (CN) during an emotional maintenance task in which participants were presented an initial image for 3 seconds and then required to maintain a mental representation of the intensity that image over a delay period of varying lengths and determine whether the initial image was more or less intense than the second image. The Late Positive Potential (LPP) was used as a neurophysiological marker of emotional maintenance during the delay period. SCZ showed normal in-the-moment emotion experience to positive stimuli; however, SCZ rated negative and neutral pictures as more intense than CN. SCZ also displayed deficits in emotional

maintenance accuracy. Furthermore, ERP data indicated reduced LPP amplitude during picture viewing for SCZ compared to CN, and only CN showed persistence of the LPP for positive stimuli into the offset delay period for approximately 1 second and this was significantly associated with behavioral emotional maintenance performance. Behavioral emotional maintenance performance also significantly predicted clinically rated negative symptoms (motivation and pleasure) and poor functional outcome. Thus, impairments in emotional maintenance may offer a promising new theory as to why people with SCZ fail to pursue goal-directed activities.

THE NEUROPHYSIOLOGICAL BASIS FOR EMOTIONAL MAINTENANCE AND REDUCED GOAL-DIRECTED BEHAVIOR IN SCHIZOPHRENIA

By

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Chapter 1: Introduction

SCHIZOPHRENIA AND EMOTION

Schizophrenia is a severe mental disorder that affects between 0.4% to 0.7% of the population (Bhugra, 2005; Saha, Chant, Welham, & McGrath, 2005; World Health Organization, 2012). This disabling psychiatric disorder is markedly heterogeneous, consisting of positive symptoms (e.g., hallucinations, delusions), negative symptoms (e.g., flat affect, lack of pleasure, low motivation to engage in activities), and cognitive functioning decline (e.g., impairments in attention, abstract thinking, and problem solving). Negative symptoms are a core feature of schizophrenia (SCZ) and include deficits such as asociality, restricted affect, anhedonia (diminished experience of pleasure), and avolition (reduced motivation to seek and persist in goal-directed behavior) (Barch & Dowd, 2010). These emotional abnormalities have been linked to impaired functional outcomes, including reduced vocational and social functioning, such as unemployment, social isolation, deteriorated familial relationships, and diminished quality of life (Hunter & Barry, 2011; Marder & Fenton, 2004; Rabinowitz et al., 2012; Strauss et al., 2013a). Negative symptoms also show little change in response to current pharmacological treatments, and psychosocial interventions show modest benefits (Leucht, Pitschel-Walz, Abraham, & Kissling, 1999; Montgomery &van Zwieten-Boot, 2007). Understanding the psychological and neural underpinnings of affective abnormalities and negative symptoms in SCZ may thus be an important first step in developing new treatments and improving functional outcome in individuals with the disorder.

The past several decades of experimental research have shed light onto the nature of emotional abnormalities in SCZ, but have also raised some important new questions. Experimental studies show clear evidence for restricted affect in face and voice in response to stimuli intended to elicit emotion (see Kring & Moran, 2008 for review). However, the expression of emotion and experience of emotion may be disconnected in SCZ, as patients often report feeling positive and negative emotions just as intensely as their healthy counterparts, despite reductions in expression. Indeed, recent reviews and meta-analyses of laboratory-based studies indicate that people with SCZ report experiencing as much emotion as controls (CN) in response to laboratory-based paradigms (Cohen & Minor, 2010; Kring & Moran, 2008), and recent real-world experience sampling studies have indicated similar findings showing no evidence for consummatory, or in-the-moment, pleasure deficits in SCZ when patients are engaged in activities relative to CN (Gard, Kring, Gard, Horan, & Kring, 2007; Oorschot et al., 2011).

Although hedonic experience may be intact in people with SCZ, it is clear that patients still display reductions in pleasure-seeking behavior. Evidence for this comes from experience sampling studies indicating that patients have a reduced frequency of engaging in pleasurable activities (Delespaul, 1995; Myin-Germeys, Nicolson, Delespaul, 2001; Oorschot et al., 2011), as well as from clinical negative symptom scales (e.g., Scale for the Assessment of Negative Symptoms (SANS); Andreasen, 1984). How is it that patients manage to have a normal capacity for pleasure, yet still not pursue pleasure-seeking activities frequently? Why do these normal hedonic experiences not motivate goal-directed behavior aimed at obtaining rewards? Given the effect of avolition on functional outcome in the community, it is of critical importance that research address these questions.

One prominent explanation is that people with SCZ have anticipatory pleasure deficits that prevent them from anticipating that future events will be pleasurable or prevent them from experiencing pleasure in the anticipation of things to come. These deficits among people with SCZ have been well documented in studies using self-report, physiological, behavioral, and fMRI methods (Burbridge & Barch, 2007; Gard, Kring, Germans Gard, Horan & Green, 2007; Horan et al., 2010; Juckel et al., 2006). Further, Kring and colleagues (2011) suggest that anticipatory pleasure is one aspect of the time course of emotion as proposed by Davidson (1998), but what sets the stage for anticipatory pleasure deficits?

One promising explanation for why patients have difficulties in translating normal hedonic experience into motivated behavior involves the idea that patients have difficulty forming mental representations of affective "value" that are crucial for guiding decision-making and goal-directed activities (Barch & Dowd, 2010; Gold, Waltz, Prentice, Morris, & Heerey, 2008). Heerey and Gold (2007) have indicated that reductions in goal-directed behavior are predicted by difficulties generating a mental representation of value to guide action selection. Furthermore, people with SCZ discount the value of future rewards more steeply than CN, but demonstrate intact ability in weighing potential immediate gains of rewards (Heerey, Robinson, McMahon, & Gold, 2007). One possibility that these studies leave open is that difficulty translating normal emotional experience into goal-directed behavior results from impairments in generating or maintaining emotional experience in the absence of a stimulus and using that mental representation of value to guide decision-making and action. Such deficits could be expected to arise from abnormalities in working memory that interact with emotional experience to cause mental representations of value to carry less weight in patients; for example, deficits in working memory may hinder the formation or maintenance of mental representations of affective value. The literature on emotional maintenance in healthy individuals provides a conceptual framework, well-validated experimental paradigms, and neurophysiological measures that are ideal for answering the question of whether impairments in emotional maintenance predict reduced goal-directed behavior in SCZ. It is currently unclear whether the disjunction between emotional experience and motivated behavior is due to difficulty generating or maintaining a mental representation of value and which neural processes are associated with deficits in these areas.

TIME COURSE OF EMOTION

In order to understand the maintenance of emotion in the absence of an emotional stimulus and how it may affect decision-making and goal-directed behavior, it is first necessary to understand the time course of emotional experiences in the presence of an evocative stimulus. The theory of affective chronometry is a popular model of the time course of emotional experience, and it states that there are two key elements of the temporal dynamics of an emotional experience: 1) the time from the onset to the peak intensity of the emotional experience and 2) the recovery time, or time it takes for the emotional experience to resolve (Davidson 1992, 1994, 1998). The recovery time involves the persistence, or attenuation, of an emotional experience after the emotion-eliciting stimulus is removed from view. Research with healthy individuals shows that emotional responses persist beyond emotional stimulus offset from studies using self-report (e.g., Frost & Green, 1982; Garrett & Maddock, 2001), corrugator electromyographic activity (e.g., Bradley, Cuthbert,& Lang, 1996; Sirota, Schwartz, & Kristeller, 1987), pupillary dilation (e.g., Siegle, Granholm, Irgram, & Matt, 2001), amygdala activity (e.g., Siegle, Steinhauer, Thase, Stenger, & Carter, 2002), and EEG asymmetry (e.g., Jackson et al., 2003). Research from affective neuroscience also shows that the persistence of an emotional experience may predict better memory for emotional pictures (Koenig & Mecklinger, 2008). The findings of these studies suggest that emotional experiences are not entirely temporally constrained by the presence of an eliciting stimulus, but instead vary in their peak and duration after stimulus offset. Furthermore, the persistence of an emotional experience may be a mechanism by which to enhance the encoding of emotional experiences, potentially allowing for the generation and maintenance of mental representations of value over a delay period.

Assessing the Time Course of Emotional Experience

As noted above, several studies have examined the time course of emotional experience (the peak of the emotional experience and the persistence of that emotional experience) in healthy populations using different methods. One such method is the affective startle modulation paradigm, in which activation of the motivational systems (approach and avoidance) exerts a modulatory influence on the defensive startle response (e.g., Lang, 1994, 1995; Lang, Bradley, & Cuthbert, 1990, 1997). In these experiments, participants are presented with negatively valenced, positively valenced, and neutral visual stimuli while physiological recordings are taken from electrodes placed near the eye (near the orbicularis oculi muscle region). These electrodes are used to record the magnitude of the eye blink via electromyography (EMG) signals when an acoustic startle probe is presented. Acoustic startle probes are periodically generated during picture presentation and/or picture offset via a loud white noise burst. Startle probes are presented during picture presentation to provide an index of the peak of the emotion experience, whereas startle magnitude following the offset of the pictures is taken to reflect the recovery, or persistence, of the emotional experience (Davidson, 1998). Used this way, startle probe methods provide information on the time course of emotional experience. Results typically indicate that negative images create greater startle blink than neutral or positive images, which is thought to occur because negatively valenced material engages the avoidance motivational system. In contrast, the attenuated startle blink response to positive stimuli is thought to reflect engagement of the approach motivational state that primes appetitive behaviors.

Studies have applied the startle paradigm to examine the startle reflex after stimulus offset. Typically, during the offset period, participants are asked to either explicitly imagine the picture or to maintain their emotion so that participants may report on their experienced emotion after the offset period. Using evocative pictures, studies have found that affective modulation of the startle response is maintained following picture presentation. Specifically, startle blink responses following the offset of unpleasant emotional stimuli are larger than startle blink responses following the offset of neutral or pleasant stimuli (Bradley, Cuthbert, Lang, 1996; Gard, &

Kring, 2007; Jackson et al., 2003; Schupp, Cuthbert, Bradley, Birbaumer, & Lang, 1997).

The time course of emotional response has also been assessed using the event-related potential (ERP) technique. ERPs are voltage fluctuations in the electroencephalogram (EEG) that are time-locked to internal or external events, such as stimuli, responses, or decisions (Luck et al., 2011). ERPs are usually isolated from the ongoing EEG by a signal averaging procedure, revealing a sequence of positive and negative peaks that are related to the event of interest (Luck et al., 2011). In other words, ERPs measure electrical activity the brain produces in response to a discrete event, such as an emotional stimulus. ERPs typically originate from postsynaptic potentials in cortical pyramidal cells arising from the flow of ions across the cell membrane in response to neurotransmitters binding with receptors (Luck et al., 2011). When postsynaptic potentials occur simultaneously in similarly oriented neurons, the resulting field potentials summate and the voltage can be detected instantaneously on the scalp (Luck et al., 2011). Therefore, ERPs reflect the firing of many neurons in synchrony in response to an event of interest. A particular advantage of ERP is the ability to provide a direct and precise millisecond-resolution measure of neural activity. For this reason, neuroscientists have developed electrophysiological paradigms using ERPs to study the time course of neural responses to emotional stimuli.

There are several ERP components that have been deemed sensitive to the emotional nature of stimuli. The most studied and well-validated component is the late positive potential (LPP), which is proposed to index augmented attention to arousing stimuli (Schupp, Junghofer, Weike, & Hamm, 2003). The LPP is a slow and sustained positive ERP that has a posterior midline scalp distribution elicited by pleasant and unpleasant stimuli (Cacioppo, Crites, Gardner, & Bernston, 1994; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Hajcak & Olvet, 2008; Schupp, Junghofer, Weike, & Hamm, 2004). The LPP is maximal at posterior-superior sites and its onset is as early as 200 ms after stimulus presentation.

The LPP can be meaningfully divided into multiple time windows. The early LPP is thought to reflect allocation of attention to emotional stimuli (anywhere from 200 ms – 1000 ms depending on the paradigm/study), and may index the peak intensity of an emotional experience (Olofsson, Nordin, Sequeira, & Polich, 2008). The late LPP (> 400 ms depending on the paradigm/study) reflects the processing and encoding of motivationally relevant emotional stimuli (Olofsson et al., 2008). In general, several studies show that the LPP is highly sensitive to the emotional nature of stimuli, appearing larger for both pleasant and unpleasant stimuli compared with neutral stimuli (Cuthbert et al., 2000; Hajcak, Moser, & Simons, 2006; Hajcak & Nieuwenhuis, 2006; Hajcak & Olvet, 2008; Keil et al., 2002; Lang et al., 1997; Schupp et al., 2000; Schupp et al., 2003).

There is also considerable evidence to indicate that an increased LPP persists following emotional picture offset (Hajcak et al., 2010; Hajcak & Olvet, 2008; MacNamara & Hajcak, 2010). To date, only one study by Hajcak and Olvet (2008) has directly examined ERPs both during and after stimulus presentation. This study presented 120 pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) of neutral, positive, and negative valence to 17 healthy undergraduates. Each picture was displayed for 2000 ms followed by a fixation point (intertrial interval) presented for 1500 ms. Specifically, the LPP was evaluated in two time windows: during stimulus presentation (400 – 2000 ms) and after picture offset (2000 – 3000 ms). To better examine the time course of the LPP after picture offset, the LPP was analyzed in successive 200 ms windows at superior recording sites. Consistent with their hypotheses, Hajcak and Olvet (2008) found that the LPP was larger after the presentation of both pleasant and unpleasant as compared with neutral pictures, and the LPP during picture presentation was larger for unpleasant than pleasant pictures. In terms of the temporal course of this effect, the LPP continued longer after unpleasant than pleasant stimuli after picture offset such that the LPP elicited by unpleasant as compared to neutral pictures differed for at least 1000 ms after picture offset, whereas the LPP elicited by pleasant pictures differed from neutral pictures for 800 ms after picture offset. Importantly, this study demonstrated that the LPP persists after picture presentation and that the LPP can be used to study neurophysiological activity following emotional stimuli.

In summary, the LPP can be used to study the time course of emotional experience and may predict a person's ability to hold a mental representation of an emotional experience. The ability to hold such experiences in working memory by generating a mental representation of value may be critical for guiding goal-directed behavior. Given evidence for the persistence of the LPP, neurophysiological ERP measures may be ideal for indexing the cognitive and neural substrates of maintaining a mental representation of value.

EMOTIONAL MAINTENANCE

Emotional maintenance is a person's ability to hold an emotional experience in order to guide goal-directed behavior (Broome, Gard, & Mikels, 2011; Gard et al., 2011). For a real-world example imagine a person in a movie theater watching several movie trailers. This person will experience an emotion for each movie trailer and then need to generate and hold a mental representation that is salient enough to compare it with other movie trailers to then guide decision-making and select which of these movies to watch in the future. Thus, emotional maintenance is an active process that requires experiencing an emotion and maintaining it by forming a mental representation of value that will ultimately guide goal-directed behavior.

Emotional maintenance is tied to the persistence of emotion in meaningful ways. The persistence of emotion, as indexed by the latter window of the LPP, may be an important predictor of emotional maintenance ability. The persistence of an emotional experience after stimulus offset is typically brief (Davidson, 1998), but the longer this persistence lasts, the more likely one may be to encode the emotional experience into a salient mental representation of value that will lead to more adaptive decision-making in the service of a goal.

To assess the maintenance of emotion, Mikels and colleagues (2005, 2008) developed an affect maintenance task. This behavioral task required participants to maintain the emotional intensity elicited by a static image over a delay period and then compare the intensity of that reaction to a second feeling evoked by a second image of greater or lesser intensity. This task was modeled after standard delayed response tasks used to test working memory (e.g., D'Esposito et al., 1998; Goldman-

Rakic, 1987). The task required that participants experience positive and negative feelings elicited by IAPS pictures. The target image was presented for 5 s, immediately followed by a retention period (3 s), and a second image (5 s). A cognitive analog task to control for visual working memory was also developed for use along with the affective maintenance task, in which subjective brightness derived from a static image was held in memory and later compared to the brightness of a second image. In general, results reflected that healthy people are able to maintain the representation of an intensity state over a delay and they are able to use that representation to guide decision-making. A study by Broome, Gard, and Mikels (2011) examined the reliability of this affect maintenance task over two experimental sessions separated by one week. Results suggest that this paradigm is a reliable measure of emotion maintenance, underscoring the utility of this measure as an assessment tool for normative and clinical populations.

MAINTENANCE OF EMOTION AND GOAL-DIRECTED BEHAVIOR IN SCHIZOPHRENIA

Using Mental Representations of Value to Guide Goal-Directed Behavior in Schizophrenia

It is well documented that SCZ patients have deficits in adaptive, goal-directed behavior (Crespo-Facorro et al., 2001; Herbener & Harrow, 2002; Torres, O'Leary & Andreasen, 2004) that contributes to functional impairment (Poole, Ober, Shenaut, & Vinogradov, 1999; Velligan et al., 1997). A possible explanation as to why people with SCZ experience deficits in goal-directed behavior is that motivational problems are due to poor coupling of affect with behavior – the failure of a salient emotional experience to motivate an appropriate response (Heerey & Gold, 2007; Schmidt et al., 2001). In the absence of a stimulus to evoke an emotional experience, people need to generate or maintain a mental representation of a stimulus that is intense, or salient, enough to guide adaptive decision-making. Working memory capacity may be critical in this process. It has been well established that people with SCZ show deficits in working memory function (Lee & Park, 2005). Thus, working memory ability may be related to the degree to which stimulus salience and motivated responding are coupled among people with SCZ.

A study by Heerey and Gold (2007) addressed the relationship between the ability to represent the value of an experience and decision-making. In this two-condition behavioral study of motivational engagement participants with and without SCZ viewed emotionally evocative pictures and they were asked to press a button quickly to see it again (for positive images) or not to see it again (for negative images) in a later condition. In the representational responding condition, button pressing took place after the image was removed from view for three seconds, and in the evoked responding condition, speeded button pressing began during picture viewing and participants pressed the button to either increase or decrease their viewing times while the stimuli were in view. Group differences emerged in the representational condition, in which participants were asked to maintain a representation of the pictures in their mind to guide their behavior (i.e., button pressing). CN pressed the button more frequently for the emotional than neutral pictures, but participants with SCZ did not show such a pattern of button pressing – they made fewer button presses to both positive and negative images than CN, although the overall number of presses did not differ between groups. This study also found that the degree of correspondence between value representation and response generation was correlated with standard working memory measures, such that better working memory predicted better correspondence. The results of this study demonstrated that SCZ involves a failure to accurately use representations of emotional experience to guide behavior, as participants with SCZ showed deficient ability to couple their behavior to the motivational properties of a stimulus.

To extend this study, Heerey et al. (2007) examined how patients weigh the relative value of immediate compared to delayed future rewards. Participants were asked to choose between smaller immediate rewards and larger delayed rewards in a monetary delayed discounting task. This delayed discounting task required that participants weigh two different reward magnitudes (e.g., larger delayed rewards vs. smaller immediate rewards) while also considering the time interval involved. Results showed that patients chose much smaller immediate rewards over larger delayed rewards than healthy CN, and patients with better working memory showed less severe discounting of future rewards. Results suggest that patients have difficulty representing the value of future outcomes, and this may partly explain why patients have problems engaging in and following through with goal-directed behavior. Paradoxically, patients with higher negative symptoms tended to display more future oriented decision-making. To explain this, the authors suggest that negative symptoms may dampen the pleasure associated with immediate rewards (Juckel et al., 2006).

Heerey and colleagues’ (2007) findings with regard to steeper delayed discounting in SCZ have been replicated by Ahn and colleagues (2011) and Heerey, Matveeva, and Gold (2011). It is important to note that certain aspects of these recent studies are inconsistent with Heerey et al.'s (2007) findings. In terms of negative symptoms, Heerey and colleagues (2011) found quite the opposite from their previously reported (Heerey et al., 2007) results. Specifically, higher negative symptom levels (e.g., avolition and anhedonia) were correlated with more impaired future representations of reward. Another study by Ahn and colleagues (2011) found that the discounting rate in SCZ was not related to negative symptoms. This study also found that the discounting rate between people with SCZ and bipolar disorder did not differ from each other, although both patient groups differed from CN. This indicates that steeper delayed discounting is not unique to SCZ. Overall results from these studies indicate that people with SCZ may have trouble representing value for future rewards, however it is unclear to what extent negative symptoms are related to this impairment.

Finally, Heerey, Bell-Warren, and Gold (2008) investigated whether patients were characterized by decision-making deficits despite intact in-the-moment reward sensitivity. Participants were presented with an implicit learning task (i.e., line discrimination task with pseudo-random reinforcement) to discern whether participants with SCZ and CN differed on reward sensitivity. Participants also completed a probabilistic decision-making task in which participants had to choose which of two gambles they wanted to play. The two gambles differed in the magnitude of reward (ranging from $3 to $17) and the probability of winning. In some trials, losing the gamble incurred a loss and on other trials no loss was possible.

Results on the implicit learning measure demonstrated that the experience of reward and ability to learn from reinforcement were intact in SCZ. On the decision-making task, patients did not differ from CN in the degree to which they weighted potential gains or uncertainty in their decisions; however, the possibility of losing had less of an influence on patients' choices than CN. Degraded working memory in patients further compromised the ability to weigh potential outcomes effectively during decision-making. The results of this study demonstrate that patients are sensitive to reward and can modify responses on the basis of reinforcement. Despite this, patients, relative to CN, show a pattern of altered decision-making that suggests they have difficulty using affective information to guide decision-making.

Taken together, these results suggest that deficits in goal-directed behavior in SCZ occur in the context of normal evoked emotional experience. The failure of normal emotional experience to facilitate goal-directed behavior may be a consequence of difficulties generating and using internal representations of emotional experiences, previous rewards, and motivational goals (Barch & Dowd, 2010). Furthermore, working memory deficits in SCZ may impact goal-directed decision-making and behavior. The maintenance of emotion is thought to facilitate goal-directed behavior, therefore it is important to understand how deficits in maintaining emotion may explain why people with SCZ engage in less goal-directed behavior.

<u>Maintenance of Emotion in Schizophrenia</u>

These studies indicating that deficits in goal-directed behavior are associated with difficulty forming mental representations of value are conceptually related to another line of work on the maintenance of emotion in SCZ. To date, only three studies have investigated the maintenance of emotion in SCZ, and these studies have found that emotional maintenance seems to be impaired in people with SCZ compared to CN. First, an event-related fMRI study by Ursu and colleagues (2011) examined the neural correlates of cognitive control processes related to maintaining emotional experience in SCZ. Participants viewed emotional pictures for 5 s, followed by a 12.5 s maintenance period in which participants viewed a fixation point. After the maintenance period, participants rated how positive, negative, and energizing the pictures made them feel. Results showed that SCZ and CN showed comparable regions of brain activity while viewing emotional pictures; interestingly, people with SCZ diverged in brain responding from CN after picture offset. Both groups showed activation of the dorsolateral prefrontal cortex (DLPFC), orbitofrontal and ventromedial PFC, and amygdala during picture presentation, but only CN continued to exhibit activity in the dorsolateral, orbitofrontal, and ventromedial PFC following picture offset. Results also showed that activity of the DLPFC in the left hemisphere after the delay in trials with pleasant stimuli was negatively correlated with anhedonia ratings in patients. Correlations between brain activity and overall severity of symptoms as indexed by the Brief Psychiatric Rating Scale (BPRS; Overall & Gorham, 1962) were not significant. Results of this study suggest that SCZ may be characterized by a failure of prefrontal circuitry after the offset of an emotional stimulus.

In another study, Kring, Germans Gard, and Gard (2011) examined the time course of emotional responding by examining affective modulation of the startle response during and after the offset of emotional stimuli in people with and without

SCZ. Participants viewed positive, negative, and neutral pictures for 6 s, followed by a 5 s delay period, during which startle probes were presented on select trials. After the blank screen, participants rated their experienced valence and arousal at the end of each trial. Startle probes were presented either during picture presentation (3500 ms after picture onset) or during the intertrial interval period (2500 ms after picture offset). Participants with SCZ reported similar emotional experiences to pictures as CN, and eye-blink magnitude/startle modulation response did not differ between people with and without SCZ during stimulus presentation. Both groups showed heightened startle while viewing negative pictures and diminished startle while viewing positive pictures. However, only CN continued to exhibit the affective modulation of the startle response after the emotional pictures were removed from view. In other words, people with SCZ did not show this continued engagement of motivational systems once the evocative pictures were removed from view, thus implying that the emotional response generated by the pictures failed to persist after stimulus offset. Of note, this study did not report on negative symptom correlates.

The studies by Ursu et al. (2011) and Kring et al. (2011) examined the persistence of neurophysiological response following an emotion induction, and provided converging evidence that the effects of emotional stimuli may be normal during stimulus exposure but reduced following stimulus offset. One limitation of these studies is that they did not ask subjects to “maintain” their emotional experience during the delay period following picture offset to then perform a behavioral decision-making task. However, a recent study by Gard et al. (2011) extended this research by using the behavioral task originally developed by Mikels and colleagues

(2005, 2008) to examine people's ability to maintain an emotional experience over a short delay and perform a decision-making task regarding emotional intensity. In Gard et al.'s (2011) study, participants viewed an emotionally evocative target picture for 5 s, followed by a 3 s retention period in which participants were specifically asked to hold the intensity of the image. This was followed by a probe image presented for 5 s. During a response period, participants were asked to compare their experience of the target image to that of the probe image by rating whether the probe was experienced as more or less emotionally intense than the target. Participants later rated their in-the-moment experience of intensity to all images to evaluate emotion maintenance accuracy. Percentage accuracy scores were determined by comparing participant responses in the maintenance task to the in-the-moment experience ratings. Participants also completed an analogous brightness maintenance task to control for visual working memory. As expected, people with SCZ did not differ from CN in their in-the-moment ratings of emotional images for positive or negative stimuli; however people with SCZ were significantly more impaired in their ability to maintain the experience of emotional intensity of the target image over a delay for both positive and negative images, as determined by maintenance accuracy scores, even after controlling for deficits in visual working memory on the brightness task. In other words, people with SCZ demonstrated emotion maintenance deficits compared to CN, and these impairments were not fully accounted for by general working memory impairments. Furthermore, in people with SCZ, impaired performance on maintenance of negative emotion was associated with lower self-report ratings of motivation. Taken together, these results are consistent with the notion that deficits in maintaining a mental representation of affective stimuli are important predictors of motivated behavior in SCZ.

An Alternative Electrophysiological Approach to Studying Emotional Maintenance in Schizophrenia

To date, few studies have examined the electrophysiological components related to the time course of emotional responding to emotional stimuli in SCZ. A study by Horan, Wynn, Kring, Simons, and Green (2010) investigated the time course of emotion during stimulus viewing. This study employed a passive viewing picture paradigm consisting of pleasant, unpleasant, and neutral pictures. Horan et al. (2010) examined two late latency components, the LPP and the P3. The P3 component starts at 300 ms post stimulus onset, and its amplitude is larger for both pleasant and unpleasant pictures compared to neutral pictures. This study also examined differences in earlier ERP components, such as the P1 (100 – 200 ms) and P2 (200 – 300 ms). Participants' EEG activity was continuously recorded during the picture-viewing paradigm. Each trial began with a 500 ms fixation screen followed by a blank screen presented for 300 ms. This was followed by a picture presented for 6 s and then an inter-trial interval which ranged from 8 s to 10 s. After the EEG recording session, participants rated each picture for experienced valence and arousal. People with SCZ demonstrated a pattern of intact behavioral responses (i.e., reported experience, viewing time) and initial ERPs. Despite reporting elevated trait social and physical anhedonia, patients demonstrated similar self-reported valence ratings of the stimuli, and had similar amplitudes for emotional stimuli on P1, P2, and P3 ERP components. However, people with SCZ, displayed diminished differentiation between pleasant versus neutral stimuli during the late-latency (500–1000 ms) LPP interval. This difference suggests a disturbance in the time course of responding to pleasant stimuli in SCZ. Specifically, both groups demonstrated a similar pattern of early ERP responses (P1, P2, P3) suggesting intact early neurophysiological responsiveness to emotional stimuli; however, the diminished LPP amplitude for pleasant stimuli indicates that later emotional processes, such as sustained attention, may be impaired in SCZ. Of note, trait physical anhedonia was correlated with smaller P2 responses during the unpleasant condition, and scores on the trait social anhedonia and the Scale for the Assessment of Negative Symptoms (SANS; Andreasen, 1984) subscales were not significantly correlated with ERP components.

Another study by Horan, Foti, Hajcak, Wynn, & Green (2012) examined whether patients show intact ERPs to task-irrelevant emotional images. The study employed a modified visual P300 task that involved rare target letter stimuli intermixed with irrelevant IAPS images of varying emotional content. This study found normal early (early posterior negativity; EPN) and late (LPP) emotion-modulated ERPs in SCZ, such that the EPN (200–300 ms) and LPP (400–1000 ms) were larger for both pleasant and unpleasant versus neutral pictures. The ERP variables showed no significant correlations with BPRS positive, negative, and total symptom scores. In sum, this study found normal early and late emotion-modulated ERPs in SCZ to task-irrelevant emotional stimuli signifying intact automatic attention to emotional stimuli. It will be imperative to determine whether LPP amplitude persists after stimulus offset. Taken together, these studies provide support for studying neural responding to emotional stimuli using ERP methodology in SCZ.

METHODOLOGICAL LIMITATIONS OF CURRENT STUDIES

Little is still known about emotional maintenance in SCZ. There are a handful of studies that have investigated this construct, and most have focused on the persistence of emotion as opposed to the maintenance of emotion to guide goal-directed behavior. For example, Usru et al. (2011) and Kring et al. (2011) focused on examining the persistence of emotion, and did not include a decision-making component that builds in behavioral demands that actually require the active maintenance of emotion. Another limitation is that these studies did not explicitly ask participants to maintain their emotional experience over a delay period. Gard et al.'s (2011) study addressed some of these issues by asking participants to hold the emotional intensity of the emotion they experienced and by including a decision-making component after the maintenance period. A limitation of this study is that it did not address whether deficits in emotional maintenance were actually due to difficulties making relative value judgments. It is important to examine this to rule out the possibility that the emotional maintenance deficits observed by Gard et al. (2011) might be due to difficulty in simply comparing emotional experiences.

Also, the studies described above and the ERP studies by Horan and colleagues (2010; 2012) give no indication of the neurophysiological underpinnings of emotion maintenance deficits. These studies demonstrate that people with SCZ show intact early processing of emotion while viewing emotional stimuli, but it remains unclear whether neurophysiological activity changes while a person is actively maintaining an emotional experience. Thus, using ERP methodology to investigate LPP amplitude throughout stimulus presentation and during an offset/maintenance period could provide insights as to the time course of emotion (peak and persistence) and whether the ability to hold a mental representation of value in the absence of a stimulus can effectively guide decision-making.

Another limitation is that few of the studies described above accurately measure negative symptoms in relation to emotional maintenance. Kring et al. (2011) did not examine whether emotion maintenance deficits were related to negative symptoms, such as avolition or anhedonia, which have been linked to decreased goal-directed behavior. Other studies that did examine negative symptoms used measures that are not optimal. For example Gard et al. (2011) measured motivated behavior based on clinician ratings (Positive and Negative Symptom Scale (PANSS); Kay, Fiszbein, & Opler, 1987) and one item of motivation on a quality of life measure. When measuring negative symptoms, other measures such as the Clinical Assessment Interview for Negative Symptoms (CAINS; Kring, Gur, Blanchard, Horan, & Reise, 2013), may assess negative symptoms more accurately. For example, the CAINS addresses conceptual and psychometric limitations of existing instruments by systematically assessing negative symptoms with a focus on capturing the underlying processes that go awry and contribute to these symptoms. Thus, items in the CAINS tap constructs covering approach motivation, pleasure, social engagement, and affective expression. Importantly, CAINS ratings combine assessments of behavioral engagement in relevant activities alongside reported experiences of motivation and emotion, enabling comprehensive assessment of the negative symptom domain and goal-directed behavior.

SUMMARY OF CURRENT KNOWLEDGE

People with SCZ report experiencing similar emotional experiences to emotion-eliciting material as people without SCZ (Cohen & Minor, 2010; Kring & Moran, 2008) even though they show reduced frequency of engaging in pleasurable activities compared to CN (Delespaul, 1995; Myin-Germeys et al., 2001; Oorschot et al., 2012). To investigate this paradox, research has begun to focus on the maintenance of emotion in SCZ and how this may explain diminished pleasure-seeking behavior despite normal emotional experience. Specifically, studies have shown that people with SCZ and CN have comparable physiological and emotional responses to affective stimuli, however, as soon as the stimuli are removed, people with SCZ are unable to maintain their emotional response compared to CN. This is important because people with SCZ demonstrate deficits in goal directed behavior, and deficits in emotion maintenance may account for these difficulties. It may be the case that people with SCZ have difficulties maintaining emotions due to difficulty maintaining mental representations of affective value that are salient enough to motivate adaptive motivated behaviors (Kring et al., 2011). To date, no studies have examined electrophysiological activity following the offset of an emotional stimulus to determine whether the persistence of neurophysiological response predicts whether SCZ will have difficulty maintaining an emotional experience to guide accurate affective decision-making.

Chapter 2: Study Hypotheses

Studies have shown that people with and without SCZ show comparable physiological response and self-reported emotional experience when presented with emotionally evocative stimuli; however, people with SCZ are unable to maintain this response after evocative stimuli are removed from view, potentially due to deficits in maintaining mental representations of emotional experiences. Despite recent research in this area, there is a dearth of research investigating the neurophysiological underpinnings of emotional maintenance in SCZ and whether aberrant neural responses predict deficits in affective decision making and real-world motivated behavior. The current study has several aims: 1) To examine whether general working memory impairments are related to emotional maintenance accuracy and the persistence of neurophysiological activity following stimulus offset, 2) To examine whether patients have difficulty maintaining a mental representation of affective value to guide decision-making, 3) To determine whether patients' deficits in emotional maintenance accuracy are predicted by reduced persistence of neurophysiological activity during maintenance delay periods of differing lengths, and 4) To investigate whether emotional maintenance accuracy and the persistence of neurophysiological response following emotional stimuli predict real-world goal-directed behavior and negative symptoms of SCZ. This study tested the following specific hypotheses:

1. Participants with SCZ would show a deficit in working memory compared to CN, as indicated by performance on the brightness maintenance control task and standard neuropsychological tests.
2. Participants with SCZ would not differ from CN with regard to self-reported emotional experience when indicating the intensity of their feelings in response to pleasant, unpleasant, and neutral stimuli.
3. Participants with SCZ would show a behavioral deficit in emotional maintenance accuracy in comparison to CN at both shorter (1.5 s) and longer (3 s) retention intervals, and these maintenance deficits would be evident for both pleasant and unpleasant stimuli.
4. Participants with and without SCZ would demonstrate comparable initial neurophysiological response to emotional stimuli during the early, middle, and late LPP windows. However only CN would continue to exhibit potentiated LPP amplitude following picture offset, and people with SCZ were predicted to show reduced neurophysiological persistence of emotional response after picture offset as indicated by lower LPP amplitude during the maintenance/delay interval.
5. For both groups, the persistence of neurophysiological response to emotional stimuli following picture offset, as indicated by LPP amplitude during the maintenance period, would predict emotional maintenance accuracy.
6. In participants with SCZ, emotional maintenance accuracy and persistence of the LPP during picture offset would predict the severity of clinically rated

negative symptoms reflecting the motivational/experiential dimension of pathology.

7. In participants with SCZ, emotional maintenance accuracy and persistence of the LPP during picture offset would predict community-based functional outcome.

Chapter 3: Methods

PARTICIPANTS

The current study included 27 participants meeting DSM-IV-TR criteria for schizophrenia or schizoaffective disorder, as determined by the Structured Clinical Interview for DSM-IV (SCID; First, Spitzer, Gibbon, & Williams, 2001) and 23 healthy control participants. Participants with SCZ were recruited from the outpatient clinics at the Maryland Psychiatric Research Center (MPRC). CN participants were recruited from random digit dialing and word of mouth among other CN recruited via random-digit dialing. CN denied a lifetime or family history of psychosis and current Axis I or II disorders according to the SCID and Structured Interview for DSM-IV Personality Disorders (SIDP-IV; Pfohl, Blum, & Zimmerman, 1997), respectively.

PROCEDURE

Participants were recruited from the MPRC as part of an ongoing study being carried out by Gregory Strauss, Ph.D. Before beginning study procedures, participants provided written informed consent, a HIPPA agreement form, and medical history screening. Competency to provide informed consent was evaluated using a standard assessment used at the MPRC, which ensures a level of understanding regarding study procedures, risks of participation, what to do if the participant no longer wishes to participate or experiences distress, and whether the participant's medications will be changed as part of the experiment.

Study procedures consisted of a clinical interview, neuropsychological evaluation, behavioral emotional maintenance tasks, and the ERP emotional maintenance task. Prior to completing the behavioral and ERP tasks, examiners trained to reliability standards conducted a clinical interview with patients, after which they completed the SCID to determine Axis I diagnosis, and several symptom severity measures including the Clinical Assessment Interview for Negative Symptoms (CAINS; Kring, Gur, Blanchard, Horan & Reise, 2013), the Brief Psychiatric Rating Scale (BPRS; Overall & Gorham, 1962), and Level of Function Scale (LOF; Hawk, Carpenter, & Strauss, 1975). Participants also completed neuropsychological testing on the MATRICS Consensus Cognitive Battery (MCCB) (Kern et al., 2008; Nuechterlain et al., 2008) as part of this or a prior study. New neuropsychological testing was completed for participants who had not received the battery within 1-year of the date of consent. ERP testing took place in the MPRC's EEG testing center, which contained a sound-attenuated chamber under controlled lighting conditions that was buffered from electrical interference. The ERP experiment (emotion intensity maintenance task) was administered prior to behavioral tasks. Behavioral testing occurred within a quite, private laboratory testing room. Participants completed the behavioral tasks in a set order – the brightness maintenance task, intensity ratings for individual slides, the preference judgment task.

MEASURES

Symptom Measures

Structured Clinical Interview for DSM-IV (SCID; First, Spitzer, Gibbon, & Williams, 2001)

Trained clinicians and research assistants administered the SCID to assess all study participants for Axis I disorders including mood disorders, psychotic disorders, alcohol and substance use disorders, and anxiety disorders. The SCID was used to verify a diagnosis of SCZ for patients and to ensure that control participants did not meet criteria for current psychological disorders.

Clinical Assessment Interview for Negative Symptoms (CAINS; Blanchard et al., 2011; Horan et al., 2011; Kring et al., 2013)

Trained clinicians administered the CAINS to participants with SCZ; a 13-item clinician measure of negative symptoms covering motivation and pleasure across social, vocational, and recreational life domains, as well as emotion expression and speech. All items are rated on a 0 to 4 scale with higher scores reflecting greater impairment. Participants were asked to report on experiences during the past seven days except for expected (anticipatory) pleasure, which covered the next seven days. The CAINS is comprised of 2 scales; the expression scale contains four items reflecting diminished outward expression and speech and the motivation/pleasure scale (MAP) contains nine items. The current study focused on the CAINS MAP to assess patients' reports of experienced motivation, interest, and emotion, as well as reports of actual engagement in goal-directed activities such as social, vocational, and recreational activities. The CAINS has demonstrated good internal consistency, test-retest stability, and interrater agreement, as well as strong convergent validity with other negative symptom measures, self-report scales of sociality, pleasure, motivation, and coded facial expressions (Kring et al., 2013). The CAINS is also related to real world vocational, independent living, and social/familial functioning (Kring et al., 2013). This measure also shows discriminant validity from depression (Kring et al., 2013).

Brief Psychiatric Rating Scale (BPRS; Overall & Gorham, 1962)

The BPRS was administered by trained clinicians. It is a 20-item interview measure that assesses current clinical symptomatology as experienced over the previous week. Items are rated on a seven-point scale, ranging from “not reported” to “very severe”. The BPRS has four subscales based on the factor structure supported by Mueser, Curran, and McHugo (1997). These factors include thought disturbance (e.g. grandiosity, suspiciousness, hallucinatory behavior, unusual thought content), anergia (e.g. emotional withdrawal, motor retardation, uncooperativeness, blunted affect), affect (e.g. somatic concern, anxiety, guilt feelings, depressive mood, hostility), and disorganization (e.g. conceptual disorganization, tension, mannerisms and posturing). Psychometric properties of the BPRS are well-established (e.g. Anderson, Larsen & Schultz, 1989; Morlan & Tan, 1998; Overall & Gorham, 1962).

Cognitive Measures

MATRICS Consensus Cognitive Battery (MCCB; Kern et al., 2008; Nuechterlein et al., 2008)

Trained clinicians administered the MCCB to all participants prior to the proposed study as part of a larger study conducted at the MPRC. The MCCB is a standardized method by which to measure cognition (Marder and Fenton, 2004). The MCCB is comprised of ten tests that assess seven cognitive domains (speed of processing, attention/vigilance, working memory, verbal learning, visual learning, reasoning and problem solving, and social cognition). Specifically, the current study used the MCCB working memory domain including spatial span and letter-number span to assess for verbal and nonverbal working memory. Psychometric properties for the tests comprising the MCCB have been well established (Green et al., 2008; Kern et al., 2008; Kern et al., 2011; Nuechterlein et al., 2008).

Functional Outcome

Level of Function Scale (LOF; Hawk et al., 1975)

Participants were administered the LOF, an interviewer-administered functioning scale containing seven items, with higher scores (on a five-point scale, 0–4) reflecting better functioning. The subscales are Social Outcome (frequency and quality of social contacts), Vocational Outcome (quantity and quality of useful work), Symptomatology (absence of symptoms and recent hospitalization), and General Functioning (fullness of life and overall level of function).

Behavioral Tasks

Brightness Intensity Maintenance Task

All participants completed a brightness intensity maintenance task to control for visual working memory, which has been found to be impaired in people with SCZ (Tek et al., 2002). In this task, participants viewed 20 neutral image pairs (40 images). The means (and standard deviations) based on IAPS normative ratings of valence, arousal, and intensity are as follows: *valence:* M=5.46 (0.71); *arousal:* M=3.48 (0.84); *intensity*: M=4.08 (1.16). Participants viewed a neutral target picture for 3 s and were asked to hold in mind the experience of the brightness intensity of the picture during a 3 s delay, followed by a neutral probe picture presented for 3 s. Using non-emotional images in the brightness task guarantees that brightness processes are kept independent of emotional processes (Mikels et al., 2005). As in the emotional intensity maintenance task, participants chose whether the second picture was more or less intense in brightness than the first picture.

Emotional Intensity Ratings

After participants completed the emotional maintenance and brightness maintenance task, they were asked to rate each emotion-eliciting picture used in the emotional maintenance task. Pictures were presented in random order and participants rated the emotional intensity experienced in that moment. There was a continuous visual analog scale under each picture (Gard et al., 2011; Mikels et al., 2005) that ranged from *not intense* to *extremely intense* (see Figure 1). Using a computer gamepad, participants indicated on a continuum how intense their experience of the picture was. The computer assigned the participant's choice a numerical value (-10 to 10) based on where the participant chose on the continuum. For each trial, participants had as much time as needed to respond.

Brightness Intensity Rating

Participants completed an analogous rating task with neutral pictures viewed in the brightness maintenance task, rating the experience of brightness intensity of each picture on a visual analog continuum, ranging from *not intense* to *extremely intense*, using the gamepad (see Figure 1).

Preference Judgment Task

To ensure that any deficits observed on the emotion maintenance task were not actually due to deficits in making comparative judgments of value, a preference judgment control task developed for the current study was administered after the emotional intensity maintenance task and emotion intensity ratings. Participants viewed 60 image pairs (from the emotional maintenance task) presented side by side, and they were asked which picture was experienced as more or less intense. Accuracy was determined in relation to normative intensity ratings.

Event Related Potential (ERP) Task

Emotional Intensity Maintenance Task

All participants completed an emotional maintenance task adapted from Gard et al., (2011) while EEG was recorded (see Figure 2). There were 80 stimulus pairs (160 images): 20 positive-positive stimulus pairs (40 total positive images), 20 negative-negative stimulus pairs (40 total negative images), and 40 neutral-emotional stimulus pairs (40 neutral, 20 positive, 20 negative images). All means (and standard deviations) based on IAPS normative ratings of valence, arousal, and intensity are as follows: *valence:* positive M=7.22 (0.63); negative: M=3.23 (0.61); neutral M=5.45 (0.46); *arousal:* positive M=5.20 (0.91); negative M=5.42 (0.83); neutral M=3.50 (0.62); and *intensity:* positive M=7.42 (1.12); negative M=7.18 (1.13), neutral M=3.97 (0.88). The 40 neutral-emotional stimulus pairs were included to allow for a comparison of the LPP for positive, negative, and neutral stimuli in the first pair position to evaluate the integrity of emotional versus neutral neuropyshiological response and replicate previous ERP effects. All 80 stimulus pairs will be presented twice (once for each condition: 1.5 s and 3 s). All images included in the task were from the International Affective Picture System (IAPS; Lang et al., 2008). Based on Gard et al. (2011), emotion-eliciting pictures were chosen to depict a wide range of content (e.g., animal and human attack, pollution, food, action scenes) and neutral images depicted household items, common daily objects, and people. All image pairs were similar in valence and arousal ratings based on normed ratings (Lang et al., 2008).

Each trial began with a positive, negative, or neutral target picture presented for 3 s, followed by a delay maintenance period of 1.5 s or 3 s, and a second picture presented for 3 s (probe). Picture pairs were positive-positive, negative-negative, neutral-positive, or neutral-negative. Participants were asked to view the target and hold the “emotional intensity” of the picture throughout the maintenance period. The reason for asking participants to remember emotional intensity is because intensity is not easily verbally encoded, and it is a psychological dimension of emotion that encompasses both valence and arousal (Feldman Barrett & Russel, 1999; Mikels et al., 2005; Reisenzein, 1994). Following the probe picture, a response window was shown in which participants were asked to choose which picture was higher in emotional intensity. Responses were made via a gamepad, such that right button press indicated the target image was more intense and left button press indicated the probe image was more intense. The order of images was presented randomly such that each image could serve either as the target or the probe. There was no limit to the amount of time for a response to occur. Immediately following the response, the next trial began.

To analyze whether participants with SCZ show less emotional maintenance accuracy compared to CN, a maintenance percentage accuracy score was computed for positive, negative, and neutral emotion conditions. Each participant’s response in the maintenance task was compared to his or her response in the in-the-moment emotion continuous rating task. Inaccurate maintenance on a particular trial occurred if the in-the-moment experience ratings differed from the maintenance comparison. In other words, if the experience of image B is rated higher than the experience of image A, but the continuous in-the-moment experience of image A is higher than that of B, this was considered inaccurate maintenance. If a participant rated their in-the-moment experience of the two images identically, these trials were not included in the analysis. Percentage accuracy for the emotion task was completed separately for positive, negative, and neutral images. Similarly, percentage accuracy scores were computed for the brightness maintenance task.

EEG Recording, Artifact Correction and Rejection, and Data Processing

Electrophysiological data was recorded from the scalp using the Neuroscan system. Electrodes were positioned in the cap using the standard 10–20 international placement system. The signals were recorded online using a right mastoid reference electrode, and the signals were re-referenced offline to the average of the left and right mastoid. The horizontal electrooculogram (HEOG) was used to measure horizontal eye movements and was recorded as the voltage between electrodes placed lateral to the external canthi. The vertical EOG was used to detect eyeblinks and vertical eye movements and was recorded from an electrode beneath the left eye. All electrode impedances were kept below 15 KΩ. The EEG and EOG were amplified by a Neuroscan Synamps amplifier with a gain of 5000, a bandpass filter of 0.05–100 Hz, and a 60-Hz notch filter. The amplified signals were digitized at 500 Hz and averaged offline. All signal processing and analysis procedures were performed in Matlab using EEGLAB toolbox (Delorme & Makeig, 2004) and ERPLAB toolbox (http://www.erpinfo.org/erplab). Data preprocessing included the removal of large muscle artifacts or extreme offsets (identified by visual inspection). Independent component analysis (ICA) was performed on the continuous data to identify and remove eye blink activity (Jung, Makeig, & Humphreys, 2000). ICA correction is preferred over rejecting trials with blinks in emotion tasks such as these given the long presentation times (3 s) and the relatively small number of trials included at each combination of stimulus type and delay period. The ICA-corrected EEG data were epoched for each trial, starting 200 ms before the onset of each target and lasting either 7500 ms or 9000 ms following target stimulus onset depending upon the delay condition (i.e., ERP averages are calculated for the full 3000 ms interval of stimulus presentation and the entire 1500 ms or 3000 ms interval after stimulus offset, and the 3000 ms probe duration).

The LPP was scored according to common conventions (e.g., Weinberg & Hajcak, 2010) at three centro-parietal electrodes: Cz, CPz, and Pz. Other electrode sites that were analyzed included Oz, P3, P4, C3, C4, Fz, FP1, FP2, VEOG, RHEOG, LHEOG, and Az. The LPP was evaluated at three time windows (Early 400–1000 ms, Middle 1000–2000 ms, and Late 2000–3000 ms) during the 3 s target presentation. The persistence of the LPP was also be evaluated after target picture offset during the maintenance/delay interval (i.e., from 3000–4500 ms or 3000–6000 ms depending upon delay condition). Similar to Hajcak and Olvet (2008), specific windows during the post-picture period were examined in smaller windows of 500 ms duration. For the 1.5 s delay this consisted of three 500 ms windows: 3000–3500 ms, 3500–4000 ms, and 4000–4500 ms. For the 3 s delay, this consisted of six 500 ms windows:

3000–3500 ms, 3500–4000 ms, 4000–4500 ms, 4500–5000 ms, 5000–5500 ms, and 5500–6000 ms.

Chapter 4: Results

OVERVIEW

Statistical analyses were conducted in several stages to evaluate the research questions and to analyze the hypotheses outlined in the previous chapters. Prior to the main analyses, all the variables of interest were examined for missing values, the normality of distributions, and outliers. Data checks were conducted to assure data met the assumptions of the planned statistics. Distributions were checked for skewness and kurtosis.

Before conducting primary behavioral analyses, groups were compared on demographic variables used in matching (age, parental education, race, sex). Next, expected group differences (SCZ < CN) in basic working memory ability were evaluated on the MCCB working memory domain and the brightness maintenance accuracy task. Group differences in subjective emotional intensity and brightness intensity ratings were evaluated, and differences in "relative" value judgment were examined on the preference judgment task to determine whether patients and CN differed in their ability to make comparative discriminations of intensity between two simultaneously presented stimuli. Finally, group differences in behavioral emotional maintenance accuracy at both shorter (1.5 s) and longer (3 s) retention intervals were assessed using a 2 (Group) × 3 (Emotion Condition) × 2 (Delay) repeated measures ANOVA.

To examine ERP data, group differences in LPP amplitude during the stimulus presentation of the first image were evaluated over early, middle, and late time windows using a 2 (Group) × 3 (Emotion) × 3 (LPP Window) repeated measures

ANOVA. Two separate repeated measures ANOVAs were used to determine group differences on the persistence of emotional response after picture offset. The LPP windows were separated into 500 ms. For the 1500 ms delay condition there were three 500 ms windows: 3000 - 3500 ms, 3500-4000 ms, and 4000-4500 ms. For the 3000 ms delay condition there were six 500 ms windows: 3000-3500 ms, 3500-4000 ms, 4000-4500 ms, 4500-5000 ms, 5000-5500 ms, and 5500-6000 ms. To directly test hypothesized LPP emotionality effects within each group, within group paired samples *t*-tests were conducted.

LPP persistence difference scores (emotional minus neutral) were calculated for each of the LPP picture offset windows, and these were used in separate stepwise (backward) regression analyses for the 1500 ms (3000-3500, 3500-4000, 4000-4500) and 3000 ms (3000-3500, 3500-4000, 4000-4500, 5000-5500, 6000-6500) conditions to predict behavioral emotional maintenance accuracy scores in SCZ and CN.

Additional stepwise backward regression analyses were conducted for the SCZ group for the 1500 ms and 3000 ms conditions to determine whether behavioral emotional maintenance accuracy scores and LPP persistence difference scores per time window predicted negative symptom severity (CAINS MAP) and functional outcome (LOF).

PARTICIPANT CHARACTERISTICS

Study procedures were completed on 34 individuals with SCZ and 27 CN participants. Seven individuals with SCZ and 4 healthy CN were eliminated due to excessively noisy EEG data following artifact correction, yielding a final sample of SCZ (n = 27) and CN (n = 23).

Demographic characteristics are presented in Table 1. The SCZ and CN groups did not significantly differ in age, parental education, sex, or ethnicity. As expected, SCZ had significantly lower personal education scores than CN. SCZ patients were prescribed the following antipsychotic medications: clozapine (12), risperidone (5), Abilify (2), olanzapine (1), haloperidol (1), fluphenazine (1), thiothixene (1), and ziprasidone (1). Two patients were prescribed more than one antipsychotic medication: clozapine-haloperidol (1) and clozapine-aripiprazole (2).

AIM 1: WORKING MEMORY

The first aim examined whether participants with SCZ would show a deficit in working memory compared to CN, as indicated by performance on the brightness maintenance control task and standard neuropsychological tests. As expected, SCZ had significantly lower MCCB working memory domain scores than CN (see Table 1). Furthermore, MCCB working memory scores were unrelated to the CAINS MAP and LOF social, work, and total scores in SCZ. The MCCB working memory domain was not significantly related to emotional maintenance accuracy or LPP amplitude during picture offset in CN (all p's > 0.05), and this was true in SCZ except for a significant correlation between MCCB working memory and neutral maintenance accuracy in the 3000 ms delay condition ($r = 0.41$, $p = 0.035$).

Groups did not significantly differ on the brightness intensity control task, $F(1, 48) = 0.02$, $p = 0.892$. Figure 3 presents mean (SE) group behavioral performance on the brightness intensity task. Brightness maintenance accuracy was based on the participant's own subjective ratings of brightness during the brightness intensity task. One way ANOVAs indicated that individuals with SCZ had significantly poorer brightness maintenance accuracy than CN for the 1500 ms, $F(1, 48) = 14.11$, $p<0.001$, partial $\eta^2 = 0.23$, and 3000 ms, $F(1, 47) = 9.06$, $p = 0.004$, partial $\eta^2 = 0.16$, conditions. For SCZ and CN, brightness maintenance accuracy scores were not significantly related to performance on the MCCB working memory domain, all *p*'s > 0.05.

AIM 2: EMOTIONAL MAINTENANCE

Aim 2 sought to examine whether patients have difficulty maintaining a mental representation of affective value to guide decision-making. Within this aim, it was predicted that SCZ would not differ from CN with regard to self-reported emotional experience when indicating the intensity of their feelings in response to pleasant, unpleasant, and neutral stimuli. However, SCZ were expected to evidence a behavioral deficit in emotional maintenance accuracy in comparison to CN at both shorter (1500 ms) and longer (3000 ms) retention intervals, and these maintenance deficits would be evident for both pleasant and unpleasant stimuli. Finally, SCZ and CN would demonstrate comparable initial neurophysiological response to emotional stimuli during the early, middle, and late LPP windows while directly viewing stimuli; however only CN would continue to exhibit potentiated LPP amplitude following picture offset, and people with SCZ were predicted to show reduced neurophysiological persistence of emotional response after picture offset as indicated by lower LPP amplitude during the maintenance/delay interval. A Greenhouse-Geisser correction was used when assumptions for sphericity were not met, and adjusted *F* and *p* values are reported.

Emotion Intensity Ratings

A repeated-measures ANOVA was conducted to examine self-reported emotional intensity in response to pleasant, unpleasant, and neutral pictures. There was a significant main effect of Emotion, $F(1.54, 72.63) = 129.33$, $p<0.001$, partial $\eta^2 = 0.73$, as well as a significant Emotion× Group interaction, $F(2, 96) = 3.87$, $p = 0.024$, partial $\eta^2 = 0.08$. There was a trend toward a significant between-subjects effect of Group, $F(1, 48) = 3.82$, $p = 0.057$, partial $\eta^2 = 0.07$. Separate one-way ANOVAs conducted to follow-up the significant interactions revealed that SCZ did not differ from CN in their in-the-moment ratings of emotional intensity for positive images, $F(1, 48) = 0.12$, $p = 0.736$. However, contrary to hypotheses, groups differed on intensity ratings for negative ($F(1, 48) = 6.71$, $p = 0.013$) and neutral images ($F(1, 48) = 5.112$, $p = 0.028$), such that SCZ rated negative and neutral pictures as more intense than CN. Figure 4 presents mean (SE) group behavioral performance on emotional intensity task.

<u>Preference Judgment Accuracy</u>

To ensure that any deficits observed on the emotion maintenance task were not actually due to deficits in making relative (i.e., comparative) judgments of value, a preference judgment control task was administered where participants viewed two images side by side and selected the image that was more intense. Participant accuracy on each trial was determined in relation to normative intensity ratings (IAPS normative valence × arousal) of each of the paired stimuli. There was a significant within-subjects effect of Emotion, $F(2, 96) = 55.38$, $p<0.001$, partial $\eta^2 = 0.54$, such that accuracy was higher for neutral ($M = 88\%$, $SD = 9.9\%$) than negative ($M = 77\%$, $SD = 12\%$) and positive ($M = 69\%$, $SD = 13.4\%$) images. However, the between-subjects effect of Group, $F(1, 48) = 2.68$, $p = 0.11$, partial $\eta^2 = 0.05$, and the Emotion × Group interaction were nonsignificant, $F(2, 96) = 0.11$, $p = 0.89$, partial $\eta^2 = 0.002$. Figure 5 presents group means and standard errors for relative value judgments across the three conditions.

Emotion Maintenance Accuracy

A 2 (Group) x 3 (Emotion) x 2 (Delay) repeated measures ANOVA was conducted to examine the hypothesis that participants with SCZ would show a behavioral deficit in emotional maintenance accuracy in comparison to CN at both shorter (1500 ms) and longer (3000 ms) retention intervals, and these maintenance deficits would be evident for both pleasant and unpleasant stimuli. There was a significant within-subjects effect of Emotion, $F(2, 96) = 19.80$, $p<0.001$, partial $\eta^2 = 0.29$, such that accuracy was higher for neutral ($M = 80.1\%$, $SD = 15.4\%$) than positive ($M = 69.4\%$, $SD = 14.7\%$) and negative ($M = 72.9\%$, $SD = 13.1\%$) stimuli. The within-subjects effect of Delay was nonsignificant, indicating that accuracy ratings were similar across 1500 ms and 3000 ms intervals, $F(1, 48) = 1.68$, $p = 0.20$, partial $\eta^2 = 0.03$. There was a significant effect of Group, $F(1, 48) = 5.153$, $p = 0.028$, partial $\eta^2 = 0.11$, such that CN ($M = 77.6\%$, $SD = 13.2\%$) had higher general accuracy than individuals with SCZ ($M = 71\%$, $SD = 14.6\%$). See Figure 6 for means and standard errors. All two and three-way interactions were nonsignificant: Delay × Group ($F(1, 48) = 0.02$, $p = 0.894$, partial $\eta^2 = 0.00$), Emotion × Group ($F(2, 96) = 0.13$, $p = 0.876$, partial $\eta^2 = 0.003$), or Delay × Emotion ($F(2, 96) = 0.97$, $p = 0.381$, partial $\eta^2 = 0.02$), or Delay × Emotion × Group ($F(2, 96) = 2.43$, $p = 0.094$, partial $\eta^2 = 0.05$). Emotional maintenance accuracy results based on normative ratings were nearly identical to emotional maintenance percentage accuracy based on participant comparisons; there was a significant within-subjects main effect of Emotion and a significant between-subjects effect of Group, but no significant interactions. See Appendix A for detailed results.

In the original data analysis plan, ANCOVA was proposed for use in the case that groups significantly differed on brightness maintenance, with brightness maintenance accuracy scores serving as the covariate. However, this approach was reconsidered and dropped given that using a variable as a covariate that is confounded by subgroup membership cannot adequately correct for a group mean (Miller and Chapman, 2001). As might be expected when ANCOVA is used inappropriately, such as this case, there were no significant main effects or interactions, all p's > 0.05.

LPP During Picture Presentation (400–3000 ms)

ERP waveforms during picture presentation and the maintenance (offset) period are shown in Figures 7 and 8 for the 1500 ms and 3000 ms conditions respectively. To examine whether participants with and without SCZ demonstrated comparable initial neurophysiological responses to emotional stimuli presented in the first position of the trial, a 2 (Group) × 3 (Emotion) × 3 (LPP Window) repeated measures ANOVA was conducted. The LPP was evaluated at three time windows during stimulus viewing (Early 400–1000 ms, Middle 1000–2000 ms, and Late 2000–3000 ms) during the 3000 ms target presentation.

In the 1500 condition, there was a significant Emotion × Group interaction, $F(2, 90) = 3.89$, $p = 0.024$, partial $\eta^2 = 0.08$, but the within-subjects effect of Emotion was nonsignificant, $F(2, 90) = 2.17$, $p = 0.12$, partial $\eta^2 = 0.05$. The within-subjects effect of LPP window was significant, $F(1.23, 55.43) = 14.46$, $p < 0.001$, partial $\eta^2 = 0.24$, such that LPP amplitude was larger for the 400–1000 ms window ($M = 2.39$, $SD = 2.72$) than the 1000–2000 ms ($M = 1.15$, $SD = 2.08$) and 2000–3000 ms ($M = 0.76$, $SD = 2.17$) windows. The between-subjects effect of Group was nonsignificant, $F(1, 45) = 0.51$, $p = 0.480$. The remaining two and three-way interactions were nonsignificant: LPP Window × Group ($F(2, 90) = 1.30$, $p = 0.277$, partial $\eta^2 = 0.03$), Emotion × LPP Window ($F(3.14, 141.21) = 1.54$, $p = 0.205$, partial $\eta^2 = 0.03$), or Emotion × LPP Window × Group ($F(4, 180) = 0.47$, $p = 0.756$, partial $\eta^2 = 0.01$). See Figure 9 for means and standard errors. Given the significant Group × Emotion interaction, follow-up one-way ANOVAs were conducted to examine potential group difference at each of the LPP windows and emotion conditions. There were no significant group differences for LPP amplitude, all *p*'s > 0.05.

Within-group paired samples t-tests were conducted to evaluate expected differences in LPP amplitude between emotional and neutral stimuli at each time window. For SCZ, the 1500 ms condition results indicated negative stimuli had significantly higher LPP amplitude than neutral stimuli at early, middle, and late windows (all *p*'s < 0.05); however, there were no significant differences in LPP amplitude for positive and neutral stimuli. There were also no significant differences in LPP amplitude for positive and negative images. For CN, positive stimuli had significantly higher LPP amplitude than negative stimuli at middle and late windows (all *p*'s < 0.05), but there were no significant differences in LPP amplitude for positive and neutral or negative and neutral stimuli.

In the 3000 condition, there was a significant within-subjects effect of Emotion, $F(2, 94) = 7.10$, $p = 0.001$, partial $\eta^2 = 0.13$, where LPP amplitude was higher for positive ($M = 1.61$, $SD = 2.95$) than negative ($M = 1.28$, $SD = 2.57$) and neutral ($M = 0.061$, $SD = 2.98$) images. The within-subjects effect of LPP Window was significant, $F(1.32, 62.15) = 12.04$, $p < 0.001$, partial $\eta^2 = 0.20$, where LPP amplitude was larger for the 400–1000 ms window ($M = 1.91$, $SD = 3.12$) than the 1000–2000 ms ($M = 0.61$, $SD = 2.24$) and 2000–3000 ms ($M = 0.43$, $SD = 2.34$) windows. There was a significant interaction between LPP Window and Group, $F(2, 94) = 3.64$, $p = 0.030$, partial $\eta^2 = 0.07$. The between-subjects effect of Group was nonsignificant, ($F(1, 47) = 0.45$, $p = 0.506$) and the remaining two and three-way interactions were nonsignificant: Emotion × Group ($F(2, 94) = 1.94$, $p = 0.149$, partial $\eta^2 = 0.04$), Emotion × LPP Window ($F(3.14, 141.21) = 1.54$, $p = 0.205$, partial $\eta^2 = 0.02$), or Emotion × LPP Window × Group ($F(4, 180) = 0.47$, $p = 0.756$, partial $\eta^2 = 0.01$). See Figure 10 for means and standard errors. To follow up the significant main effects and interactions, follow-up one-way ANOVAs were conducted to examine potential group difference at each of the LPP windows and emotion conditions. People with SCZ had higher LPP amplitude for neutral images in the Late LPP window than CN, $p = 0.017$, but there were no significant differences between SCZ and CN in the Early and Middle windows, all p's > 0.05.

Within-group paired samples t-tests for SCZ demonstrated no significant differences in LPP amplitude among emotion conditions in the Early, Middle, and Late windows (all p's < 0.05); however, for the control group, positive stimuli had significantly higher LPP amplitude than negative stimuli ($p < 0.05$) in the Early window. CN demonstrated higher amplitude of the LPP to positive and negative stimuli than neutral stimuli in the early, middle, and late windows (all *p*'s < 0.05).

<u>LPP After Picture Offset</u>

To examine whether groups differed on the persistence of their emotional response to emotional stimuli after picture offset (i.e., maintenance period), repeated measures ANOVAs were conducted separately for the 1500 ms and 3000 ms conditions.

In the 1500 condition, the within-subjects effect of Emotion was nonsignificant, $F(2, 90) = 0.99$, $p = 0.377$, partial $\eta^2 = 0.02$; however, there was a significant interaction between Emotion and Group ($F(2, 90) = 3.49$, $p = 0.035$, partial $\eta^2 = 0.07$). The within-subjects effect of LPP Window was significant, $F(1.54, 69.10) = 12.09$, $p < 0.001$, partial $\eta^2 = 0.21$, where LPP amplitude was larger for the 3000–3500 ms ($M = 1.47$, $SD = 2.46$) and 3500–4000 ms ($M = 1.47$, $SD = 2.81$) windows than the 4000–4500 ms ($M = 0.47$, $SD = 2.63$) window. The between-subjects effect of Group was nonsignificant, $F(1, 45) = 3.21$, $p = 0.080$. There was a significant interaction of Emotion × LPP Window ($F(2.53, 114.03) = 5.72$, $p = 0.002$, partial $\eta^2 = 0.11$). The remaining two and three-way interactions were nonsignificant: LPP Window × Group ($F(2, 90) = 0.60$, $p = 0.553$, partial $\eta^2 = 0.01$), or Emotion × LPP Window × Group ($F(4, 180) = 1.63$, $p = 0.193$, partial $\eta^2 = 0.04$). See Figure 11 for means and standard errors.

Follow-up one-way ANOVAs were conducted to examine potential group difference among each of the LPP windows and emotion conditions. People with SCZ had higher LPP amplitude for negative images in the 3000–3500 ms, 3500–4000 ms, and 4000–4500 ms windows than CN, (all *p*'s < 0.05). SCZ also demonstrated higher amplitude of the LPP to positive images during the 4000–4500 ms window than CN ($p = 0.044$).

Within-group paired samples t-tests were conducted to evaluate expected differences in LPP amplitude between emotional and neutral stimuli at each time window, but there were no significant differences (all *p*'s > 0.05).

In the 3000 condition, the within-subjects effect of LPP Window was significant, $F(2.33, 109.48) = 46.28$, $p< 0.001$, partial $\eta^2 = 0.50$, such that LPP amplitude decreased over time (see Figure 12). The between-subjects effect of Group approached significance, ($F\ (1, 47) = 3.95$, $p = 0.053$, partial $\eta^2 = 0.08$), where LPP amplitude appeared larger for SCZ ($M = 0.67$, $SD = 3.66$) than CN ($M = -0.85$, $SD = 3.89$). Other main effects and interactions did not reach significance: Emotion ($F(2, 94) = 1.98$, $p = 0.144$, partial $\eta^2 = 0.04$), Emotion × Group ($F(2, 94) = 1.27$, $p = 0.286$, partial $\eta^2 = 0.03$), LPP Window × Group ($F\ (5, 235) = 1.81$, $p = 0.112$, partial $\eta^2 = 0.04$), Emotion × LPP Window ($F\ (4.63, 217.73) = 1.40$, $p = 0.230$, partial $\eta^2 = 0.03$), or Emotion × LPP Window × Group ($F\ (10, 470) = 0.79$, $p = 0.641$, partial $\eta^2 = 0.02$). See Figure 13 for means and standard errors.

Within-group paired samples t-tests were conducted to evaluate expected differences in LPP amplitude between emotional and neutral stimuli at each time window. There were no significant differences in SCZ (all *p*'s > 0.05), and CN demonstrated significantly larger LPP amplitude for positive images than neutral images during the 3000–3500 ms and 3500–4000 ms windows (all *p*'s < 0.05).

LPP During Probe Picture Presentation

ERP waveforms during picture presentation and the maintenance (offset) period are shown in Figures 14 and 15 for the 1500 ms and 3000 ms conditions respectively. In the 1500 ms condition, there was a significant within-subjects effect of Emotion, $F(2, 90) = 7.32$, $p = 0.001$, partial $\eta^2 = 0.14$, where LPP amplitude was larger for positive ($M = 1.05$, $SD = 2.91$) than negative ($M = 0.56$, $SD = 3.11$) and neutral ($M = -0.24$, $SD = 2.96$) stimuli. There was also a significant within-subjects effect of LPP Window, $F(1.34, 60.17) = 31.84$, $p < 0.001$, partial $\eta^2 = 0.41$, where LPP amplitude was larger for the 400–1000 ms window ($M = 1.67$, $SD = 3.51$) than the 1000–2000 ms ($M = 0.10$, $SD = 2.48$) and 2000–3000 ms ($M = -0.39$, $SD = 2.54$) windows. The between-subjects effect of Group was nonsignificant, ($F\ (1, 45) = 1.38$, $p = 0.247$, partial $\eta^2 = 0.04$). The remaining two and three-way interactions were nonsignificant: Emotion × Group ($F\ (2, 90) = 1.22$, $p = 0.300$, partial $\eta^2 = 0.03$), LPP Window × Group ($F\ (2, 90) = 0.01$, $p = 0.993$, partial $\eta^2 = 0.00$), Emotion × LPP Window ($F\ (3.14, 141.22) = 0.30$, $p = 0.833$, partial $\eta^2 = 0.01$), or Emotion × LPP Window × Group ($F\ (4, 180) = 2.34$, $p = 0.057$, partial $\eta^2 = 0.05$). See Figure 16 for means and standard errors.

Within-group paired samples t-tests revealed no significant differences for SCZ (all p's > 0.05). For CN, positive stimuli had significantly higher LPP amplitude than negative stimuli for the 1000–2000 ms and 2000–3000 ms windows (all p's < 0.05), and positive stimuli had higher LPP amplitude than neutral stimuli for the 400–1000 ms, 1000–2000 ms, and 2000–3000 ms windows, (all p's < 0.05). At trend level, negative stimuli had higher LPP amplitude than neutral stimuli for the 400–

1000 ms, 1000–2000 ms, and 2000–3000 ms windows ($p = 0.053$, $p = 0.047$, $p = 0.065$ respectively).

In the 3000 ms condition, there was a significant within-subjects effect of Emotion, $F(2, 94) = 5.93$, $p = 0.004$, partial $\eta^2 = 0.11$, where LPP amplitude was larger for positive ($M = 3.29$, $SD = 3.26$) than negative ($M = 2.89$, $SD = 3.68$) and neutral ($M = 1.98$, $SD = 3.20$) stimuli. There was also a significant within-subjects effect of LPP Window, $F(1.39, 65.18) = 9.06$, $p < 0.001$, partial $\eta^2 = 0.16$, where LPP amplitude was larger for the 400–1000 ms window ($M = 3.59$, $SD = 3.85$) than the 1000–2000 ms ($M = 2.40$, $SD = 3.11$) and 2000–3000 ms ($M = 2.18$, $SD = 2.79$) windows. The between-subjects effect of Group was nonsignificant, $F(1, 47) = 2.27$, $p = 0.138$, partial $\eta^2 = 0.05$. The remaining two and three-way interactions were nonsignificant: Emotion × Group ($F(2, 94) = 0.20$, $p = 0.818$, partial $\eta^2 = 0.004$), LPP Window × Group ($F(2, 94) = 0.24$, $p = 0.790$, partial $\eta^2 = 0.01$), Emotion × LPP Window ($F(3.00, 141.12) = 1.13$, $p = 0.342$, partial $\eta^2 = 0.02$), or Emotion × LPP Window × Group ($F(4, 188) = 0.53$, $p = 0.718$, partial $\eta^2 = 0.01$). See Figure 17 for means and standard errors.

Within-group paired samples t-tests were conducted to evaluate expected differences in LPP amplitude between emotional and neutral stimuli at each time window. There were no significant differences for SCZ (all p's > 0.05). For CN, positive stimuli had significantly higher LPP amplitude than neutral stimuli for the 400–1000 ms and 2000–3000 ms windows (all p's < 0.05). At trend level, positive stimuli had higher LPP amplitude than neutral stimuli for the 1000–2000 ms window, $p = 0.05$.

AIM 3: LPP AMPLITUDE AS A PREDICTOR OF EMOTIONAL MAINTENANCE ACCURACY

This aim sought to determine whether the persistence of LPP in response to emotional stimuli during maintenance (offset) delay periods predicted behavioral emotional maintenance accuracy. Difference scores of mean LPP amplitude (emotional minus neutral difference) were calculated separately for each window. Higher difference scores reflect larger LPP amplitude to emotional stimuli compared with neutral stimuli. The difference scores for the 3 (1500 ms delay) and 6 (3000 ms delay) windows were used in a stepwise (backward) multiple regression analysis to predict emotional maintenance accuracy (average of positive and negative maintenance accuracy).

The correlations of the variables for SCZ and CN are presented in Tables 2 and 3. For both groups (SCZ and CN) and both maintenance delay conditions (1500 ms and 3000 ms) there were no significant correlations between emotion maintenance accuracy and the amplitude of the LPP at each time window during the maintenance period.

In the 1500 ms condition prediction models were nonsignificant for both SCZ and CN (see Tables 4 and 5 respectively). In the 3000 ms condition, the prediction model for SCZ contained four of the six predictors and was reached in three steps with two variables removed (see Table 6). The model was statistically significant, $F(4, 21) = 4.06$, $p = 0.014$, and accounted for approximately 44% of the variance in emotion maintenance accuracy in SCZ ($R^2 = .44$, Adjusted $R^2 = .33$). In SCZ, the LPP amplitude significantly predicted emotion maintenance accuracy during 3000–3500 ms, 3500–4000 ms, 4500–5000 ms, and 5000–5500 ms windows. In CN, the prediction model contained two of the six predictors and was reached in five steps with four variables removed (see Table 7). The model was statistically significant, $F(2, 20) = 4.18$, $p = 0.03$, and accounted for approximately 54% of the variance in emotion maintenance accuracy ($R^2 = .54$, Adjusted $R^2 = .30$). In CN, emotion maintenance accuracy was significantly predicted by LPP amplitude during the 3000–3500 ms and 3500–4000 ms windows.

AIM 4: EMOTION MAINTENANCE ACCURACY AND LPP AMPLITUDE AS PREDICTORS OF NEGATIVE SYMPTOMS AND FUNCTIONAL OUTCOME IN SCHIZOPHENIA

This aim sought to determine whether behavioral emotional maintenance accuracy and the persistence of the LPP in response to emotional stimuli during maintenance delay periods separately predicted negative symptom severity (CAINS-MAP; motivation and pleasure) and functional outcome (LOF) in SCZ.

Negative Symptoms and Emotional Maintenance Accuracy

Behavioral emotional maintenance accuracy scores for positive, negative, and neutral stimuli were used in a standard backward regression analysis to predict negative symptoms (CAINS MAP) in the 1500 ms and 3000 ms conditions in SCZ. The correlations among variables are shown in Table 8. In the 1500 ms condition, greater impairment on the CAINS MAP was significantly correlated with lower negative and neutral emotion maintenance accuracy, but the CAINS MAP was not significantly correlated with positive emotion maintenance accuracy. In the 3000 ms condition, the greater impairment on the CAINS MAP was significantly correlated with with lower negative, but not positive or neutral, emotion maintenance accuracy.

In the 1500 ms condition, the prediction model contained one of the three predictors and was reached in three steps with two variables removed (see Table 9). The model was statistically significant, $F(1, 23) = 5.09$, $p = 0.03$, and accounted for approximately 18% of the variance of negative symptoms ($R^2 = .18$, Adjusted $R^2 = .15$). For the 1500 ms delay, negative symptoms were primarily predicted by lower neutral maintenance accuracy.

The prediction model for the 3000 ms condition contained one of the three predictors and was reached in three steps with two variables removed (see Table 10). The model was statistically significant, $F(1, 23) = 5.03$, $p = 0.035$, and accounted for approximately 18% of the variance in negative symptoms ($R^2 = .18$, Adjusted $R^2 = .14$). For the 3000 ms delay, negative symptoms were primarily predicted by lower negative maintenance accuracy.

<u>Negative Symptoms and LPP Persistence</u>

LPP persistence difference scores per time window were used in a stepwise (backward) multiple regression analysis to predict negative symptoms. The correlations between LPP amplitude difference scores and the CAINS MAP in the 1500 ms and 3000 ms conditions are shown in Table 11. For SCZ in both maintenance delay conditions, there were no significant relationships between LPP window difference scores and CAINS MAP scores. The models for both maintenance delay conditions were not statistically significant, indicating that LPP persistence in the 1500 and 3000 ms conditions did not significantly predict negative symptoms (See Table 12 and 13).

Functional Outcome and Emotional Maintenance Accuracy

For the 1500 ms interval, people with SCZ showed significant correlations between LOF total scores and neutral emotion maintenance accuracy, but not positive or negative emotion maintenance accuracy. In the 3000 ms delay condition, there were no significant correlations between LOF total scores and positive, negative and neutral emotion maintenance. See Table 14 for correlations.

For the 1500 ms condition, the prediction model contained one of the three predictors and was reached in three steps (see Table 15). The model was statistically significant, $F(1, 24) = 6.93$, $p = 0.015$, and accounted for approximately 22% of the variance in functional outcome ($R^2 = .22$, Adjusted $R^2 = .19$). Higher neutral maintenance accuracy scores predicted functional outcome scores. The model for the 3000 ms condition was not statistically significant as seen in Table 16.

Functional Outcome and LPP Persistence

The correlations of the variables in the 1500 ms and 3000 ms conditions are shown in Table 17. There were no significant correlations between LPP amplitude difference scores and LOF total scores in the 1500 ms and 3000 ms conditions. Based on the stepwise (backward) multiple regressions, the models were not statistically significant for the 1500 ms and 3000 ms conditions (as seen in Tables 18 and 19 respectively), indicating that LPP persistence during the offset period did not significantly predict functional outcome.

Chapter 5: Discussion

DISCUSSION

The primary aim of the current study was to determine whether impairments in maintaining mental representations of affective value and using them to guide decision-making were associated with negative symptoms and poor functional outcome in individuals with SCZ. To address this question, an emotional maintenance paradigm was administered while EEG was recorded. During the emotional maintenance task, participants are presented an initial image for 3 seconds and then required to maintain a mental representation of the intensity that image over a delay period of varying lengths and determine whether the initial image was more or less intense than the second image. The Late Positive Potential (LPP), a centro-parietal midline ERP component, was used as a neurophysiological marker of emotional maintenance and the persistence of value representations during the delay period. A series of behavioral control tasks were also completed to examine competing explanations for group differences in task performance. These included separate tasks where participants made behavioral ratings of emotional intensity and brightness intensity of images, as well as a preference judgment task that required participants to select from two images presented side by side the one that was more intense.

Prior to evaluating key hypotheses related to emotional maintenance performance and its associations with clinical outcomes, it is important to know whether the SCZ and CN groups evidence similar self-reported emotional response to evocative stimuli used in the behavioral emotional maintenance task. Consistent with hypotheses, results indicated that SCZ demonstrate intact in-the-moment experience of positive stimuli. This was indicated by similar emotional intensity ratings for positive images between SCZ and CN. These findings converge with results from Gard and colleagues' (2011) behavioral emotional maintenance experiment indicating that SCZ and CN have similar intensity ratings for positive images (Gard et al., 2011). Results of this study are also consistent with larger literature indicating that SCZ display intact self-reports of valence (Cohen & Minor, 2010) and arousal (Llerena et al., 2012) for positive stimuli presented in the context of laboratory-based experiments.

However, inconsistent with hypotheses, SCZ rated negative and neutral pictures as more intense than CN. This finding differs from past findings by Gard et al. (2011), which found no differences between SCZ and CN on negative intensity ratings. In addition, these findings are inconsistent with general findings in SCZ in relation to self-reported arousal to unpleasant stimuli, as indicated by the meta-analysis by Llerena et al. (2012), which found that people with SCZ rated negative stimuli as less arousing than CN. However, increased intensity ratings for negative and neutral stimuli in SCZ are consistent with a large literature indicating that SCZ report increases in negative emotion to unpleasant, neutral, and pleasant stimuli at a medium to large effect size (Cohen & Minor, 2010). There are several potential explanations for why this occurs. First, SCZ may misattribute affective meaning to a range of neutral stimuli and this may result from increased emotional arousal (Haralanova et al., 2011; Llerena et al., 2012). Attributing aberrant salience to neutral stimuli is thought to be core to the development and maintenance of psychotic symptoms (Kapur, 2003, Kapur et al., 2005). Although aberrant salience and elevated arousal are not synonymous, it is possible that the two are related. Second, increased negative emotionality to both negative and neutral stimuli may also reflect an emotion regulation abnormality. Several recent studies have reported neurophysiological evidence for emotion regulation impairments in SCZ (i.e., difficulty decreasing negative emotion using strategies) (Strauss et al., 2013b; Horan, Hajcak, Wynn, & Green, 2013), and there is some evidence that such neurophysiological impairments are associated with elevated state and trait negative emotions (Strauss et al., 2013b). Thus, it may be that elevated intensity levels found here for unpleasant and neutral stimuli provides further evidence of an emotion regulation impairment in SCZ; patients may evidence increased reactivity to negative stimuli that results from ineffective use of emotion regulation strategies, resulting in tonic elevations in negative emotionality that bleeds into everyday experiences, including those that should be more neutral or pleasant. Notably, these interpretations are speculative. It is important to keep in mind that intensity ratings obtained in the current study reflect a combination of both valence and arousal, and it is therefore impossible to determine which of these two elements is associated with the increased intensity ratings observed in this study for unpleasant and neutral stimuli. However, based on prior literature, these findings may be consistent with the literature indicating that SCZ report increased negative emotion to a range of stimuli (Cohen & Minor, 2010; Llerena et al., 2012). Nonetheless, SCZ do indeed evidence comparable or greater emotional reactivity than CN to positive, negative, and neutral stimuli. This adds confidence to interpretations related to the emotional maintenance task, suggesting that differences observed between groups cannot be accounted for by diminished affective experience to stimuli used in the task.

On the behavioral emotional maintenance task, SCZ were expected to evidence a deficit in emotional maintenance accuracy in comparison to CN at both shorter (1500 ms) and longer (3000 ms) retention intervals; these maintenance deficits were expected to be evident for both pleasant and unpleasant stimuli. Both groups displayed better maintenance accuracy for neutral, followed by negative and then positive stimuli, and CN generally displayed better performance than SCZ across all conditions. These findings are generally consistent with Gard et al. (2011), who using this same task found SCZ significantly more impaired in their ability to maintain the experience of emotional intensity of the target image over a 3 s delay for both positive and negative images.

Importantly, we also demonstrated that this behavioral emotional maintenance deficit cannot be attributed to a simple failure to make “relative” value judgments, i.e., accurately determine which of two images presented side by side is more intense. This was indicated by accuracy on the preference judgment task, where SCZ and CN demonstrated a comparably high degree of accuracy for determining differences in stimulus intensity. These findings extend those of Gard et al. (2011), which did not include this important behavioral control task, by suggesting that maintenance accuracy deficits cannot simply be attributed to deficits in making relative value judgments about pairs of stimuli. Overall, behavioral results indicate that SCZ involves a failure to accurately use mental representations of affective value to guide decision-making.

ERP data provided some neurophysiological evidence for impaired emotional maintenance in SCZ. To determine whether emotional maintenance deficits truly reflect impairments in emotional maintenance and not simply aberrant neural reactivity to the stimuli themselves, it was important to first examine group differences in LPP amplitude during emotional stimulus viewing. It was hypothesized that SCZ and CN would demonstrate comparable initial neurophysiological response to emotional stimuli during the early, middle, and late time windows while directly viewing stimuli; however results did not support this hypothesis. In the 3000 ms condition, CN displayed higher LPP amplitude for positive and negative stimuli than neutral stimuli. These findings from the 3000 ms condition are generally consistent with the literature on the LPP in healthy individuals indicating greater amplitude for both positive and negative than neutral stimuli (Foti, Hajcak & Dien, 2009; Hajcak et al., 2013; Hajcak & Olvet, 2008; Olofsson et al., 2008; Pastor et al., 2008). In contrast, SCZ displayed no differences in LPP amplitude among positive, negative, and neutral stimuli during viewing of the target image, suggesting that the neural response to emotional stimuli was not intact. These findings are in contrast to other SCZ studies examining the amplitude of the LPP to emotional images in which SCZ generally demonstrate normal early and late ERP's to emotional versus neutral pictures during picture viewing tasks (Horan et al., 2010, 2012, 2013; Strauss et al., 2013b).

At the 1500 ms delay condition, CN only showed a tendency for higher amplitude of the LPP for positive than negative stimuli, and there were no differences between neutral and unpleasant or pleasant stimuli. It is unclear why CN did not evidence robust LPP for unpleasant stimuli in the 1500 ms condition. In contrast, at the 1500 ms condition, SCZ had significantly higher LPP amplitude for negative than neutral stimuli at early, middle, and late windows; however, there were no significant differences in LPP amplitude for positive and neutral and positive and negative images. These finding converge with results from Horan and colleagues (2010) showing that SCZ displayed diminished differentiation between pleasant versus neutral stimuli during the late-latency (500–1000 ms) LPP interval.

Persistence of the LPP during the delay interval was evaluated as a neurophysiological index of emotional maintenance. It was hypothesized that only CN would continue to exhibit potentiated LPP amplitude following picture offset (i.e., higher amplitude for emotional than neutral), and people with SCZ were predicted to show reduced neurophysiological persistence of neural response to emotional stimuli after picture offset as indicated by lower LPP amplitude during the maintenance/delay interval. Consistent with hypotheses, CN continued to show greater amplitude of the LPP after picture offset for positive than neutral stimuli for approximately 1 second in the 3000 ms condition. These findings are consistent with those of Hajcak and Olvet (2008) who found larger LPP amplitude for positive than neutral pictures for up to 800 ms; however, results diverged with that of Hajcak and Olvet (2008) who also found larger LPP amplitude for negative than neutral pictures for up to 1000 ms. In contrast, SCZ failed to show greater LPP amplitude for emotional than neutral stimuli during the 3000 ms delay interval. This is explained by their lack of difference in LPP amplitude while viewing the target image.

In the 1500 ms condition, CN failed to show greater amplitude of the LPP for emotional than neutral stimuli during the delay interval. These findings are inconsistent with this study's results from the 3000 ms condition and Hajcak and Olvet's (2008) findings indicating that the LPP is greater for emotional than neutral pictures. Likewise, SCZ failed to show greater amplitude of the LPP for emotional than neutral stimuli during the 1500 ms condition. Thus, across the 1500 and 3000 ms conditions, results provide inconsistent support for whether emotional maintenance effects exist in CN. However, there was evidence across both delay conditions for a lack of emotional maintenance in SCZ, but this may not only reflect a problem with maintenance but also initial reactivity to emotional stimuli.

We also examined whether neurophysiological persistence of the LPP predicted behavioral emotional maintenance performance in each group. During the 3000 ms condition, LPP amplitude for SCZ was predictive of emotion maintenance accuracy during 3000–3500 ms, 3500–4000 ms, 4500–5000 ms, and 5000–5500 ms windows. In CN, emotion maintenance accuracy was significantly predicted by LPP amplitude during the 3000–3500 ms and 3500–4000 ms windows. This is the first study to examine the relationship between behavioral emotional maintenance and LPP amplitude. Results provide novel evidence that reduced persistence of the neurophysiological response to emotional stimuli predicts impairments in using mental representations of value to guide decision-making. It is important to note that this interpretation should be treated with caution given the discrepant LPP results observed in the 3000 ms and 1500 ms conditions.

We also examined whether emotional maintenance accuracy and persistence of the LPP during picture offset predicted the severity of clinically rated negative symptoms of avolition and anhedonia in SCZ. In the 1500 ms condition, negative symptoms significantly correlated with negative and neutral emotion maintenance accuracy, but not with positive emotion maintenance accuracy. In contrast, negative symptoms showed a significant relationship with negative, but not positive or neutral, emotion maintenance accuracy in the 3000 ms condition. These results stand in contrast to the results of Gard and colleagues (2011) who found that emotion maintenance accuracy was not associated with clinician ratings of avolition and motivation. Moreover, results of the current study demonstrated that negative symptoms were primarily predicted by lower negative maintenance accuracy in the 3000 ms condition. However, in the 1500 ms condition, negative symptoms were primarily predicted by lower neutral maintenance accuracy. This indicates that negative symptoms are associated with deficits in maintaining stimulus representations and using them to guide decision-making. Although behavioral maintenance scores did predict negative symptoms, LPP persistence did not. These findings are consistent with several studies indicating that negative symptoms are weakly or nonsignificantly related to brain activity using ERP and fMRI techniques (Horan et al., 2010, 2012; Ursu et al., 2012).

Poor functional outcome is a major concern in SCZ given high rates of unemployment, social isolation, deteriorated familial relationships, and diminished quality of life in this population (Hunter & Barry, 2011; Marder & Fenton, 2004; Rabinowitz et al., 2012; Strauss et al., 2013a). As such, we also examined whether emotional maintenance accuracy and persistence of the LPP during picture offset would predict community-based functional outcome in SCZ. For the 1500 ms interval, better functional outcome was related to higher neutral emotion maintenance accuracy, but not positive or negative emotion maintenance accuracy. Additionally, higher neutral maintenance accuracy predicted functional outcome. These results should be interpreted with caution given results were not replicated in the 3000 ms condition. In terms of LPP persistence, the amplitude of the LPP during the offset period was not related to functional outcome in the 1500 ms and 3000 ms conditions. Furthermore, LPP persistence during the offset period did not significantly predict functional outcome. Taken together, there was some evidence that deficits in maintaining stimulus representations and using them to guide decision making were also related to poor community-based functional outcome; however, these associations were not specific to emotional stimuli, nor as strong as might be expected based on past research (Gard et al., 2011).

Summary

Overall, results supported the hypothesis that individuals with SCZ would display deficits in maintaining mental representations of value and using them to guide decision-making. However, ERP data clarified that these deficits may not only be due to problems with maintaining stimulus representations over a delay interval, but also reduced reactivity to emotional stimuli themselves to some extent. The findings indicating reduced LPP amplitude during picture viewing are consistent with some (Horan et al., 2010) but not most prior research (Horan et al., 2010, 2012, 2013; Strauss et al., 2013b). Nonetheless, persistence of the LPP for positive relative to neutral stimuli into the offset delay period for approximately 1 second was significantly associated with behavioral emotional maintenance performance, providing some assurance that emotional maintenance deficits in SCZ may indeed reflect deficits in the persistence of the neural response to emotional stimuli and not just reactivity. Behavioral emotional maintenance performance also significantly predicted clinically rated negative symptoms (motivation and pleasure) and poor functional outcome, supporting the notion that deficits in generating and maintaining mental representations of stimulus value predict reductions in goal-directed behavior. Thus, impairments in emotional maintenance may offer a promising new theory as to why people with SCZ fail to pursue goal-directed activities; although impairments in neural reactivity to emotional stimuli needs to be ruled out.

Limitations

There were several limitations to the current study. First, the current study modified the behavioral emotional maintenance task developed by Mikels et al. (2005) and used by Gard et al. (2011) to make it suitable for ERPs and to examine the questions at hand. Since the proposed study aimed to examine the LPP, the task was revised in order to include positive, negative, and neutral pictures, enabling valid comparisons of LPP across conditions in the same behavioral paradigm. Consequently, it is important to consider that modifications made to the emotional maintenance task for the purpose of the current study undoubtedly change the validity and reliability of the task, even though Broome et al. (2011) found the affect maintenance paradigm to be a reliable measure of emotion maintenance.

Second, few studies have examined whether the LPP persists beyond stimulus presentation. In fact, we are not aware of studies replicating the original Hajcak and Olvet (2008) findings of higher LPP amplitude for emotional than neutral stimuli during picture viewing in CN. It is therefore unclear whether our inconsistent findings across 1500 ms and 3000 ms conditions in SCZ and CN reflect reliability of LPP persistence or something biologically meaningful about these conditions.

Third, the ERP data did not possess good signal to noise ratio. Compared to other ERP tasks, there were relatively few trials per condition in the emotional maintenance task. Although the number of trials is not dramatically smaller than typically used in most studies on emotion using ERPs, the trial lengths used in this task were, by nature of the design, very long (e.g., 9 seconds for the 3000 ms delay condition). The length of these trials allowed for an increased likelihood of artifacts that produce noise in the EEG data (e.g., blinks, eye movements). ICA was used to correct the EEG data and minimize these issues, but it was not as effective as what might be ideal. Given the small number of trials per condition, further artifact rejection was not a valid possibility for this study. Although careful attempts were made to improve signal to noise ratio, the ability to detect true ERP differences was likely affected by the amount of noise in the EEG that resulted from long trials. To address this, further data processing will be conducted before submitting the manuscript for publication. In particular, the ERP data from both conditions (1500 ms and 3000 ms) will be combined to improve signal to noise ratio. Based on Hajcak and Olvet's (2008) study, the data will be epoched from -200 ms to 4000 ms for both the 1500 ms and 3000 ms conditions; thus the ERP averages will represent the full 3000 ms of stimulus presentation and a 1000 ms period after stimulus offset. This will reduce the number of variables and, more importantly, increase the number of trials thus improving the signal to noise ratio.

The current investigation was adequately powered to detect, at least, medium effect sizes for most of the proposed analyses. However, it was not ideally powered to explore other factors, such as sex differences or include samples of individuals with SCZ specifically selected for varying levels of negative symptom impairment. Thus, in future studies, it will be critical to include larger samples that are ideally powered for the high number of variables and relationships explored across ERP components and to examine individual differences.

Finally, all participants with SCZ were taking antipsychotic medication. Although this is common among people with SCZ and boosts generalizability, it is not clear whether the current findings reflect antipsychotic medication effects. Notably, it has been suggested that antipsychotic medications that block dopamine receptors have the potential to impact cognitive and motivational systems (Barch & Dowd, 2010). To rule out the possible effects of medications, it will be important to compare results between different medication types (e.g., typical vs. atypical antipsychotics) or determine whether a similar pattern of emotional maintenance is present when examining un-medicated high-risk populations, people in the prodromal stages of psychosis, or first-degree relatives of people with SCZ.

Directions for Future Research

A next step would be to use functional imaging to understand brain circuitry supporting the link between affect and goal-directed behavior. Ursu and colleagues

(2011) used an fMRI paradigm to examine brain activity in SCZ and CN during trials in which they viewed emotional pictures and rated their emotional experience after a delay period. SCZ and CN showed intact brain activity in the presence of emotional stimuli; however, only SCZ showed decreased activation in the dorsolateral prefrontal cortex and other prefrontal, limbic, and paralmibic areas during the delay period. Notably, participants were not asked to maintain their emotional experience over the delay period. Given the results of the current study, future fMRI studies of this nature should include instructions for participants to maintain emotional experiences over a delay period and incorporate a decision-making component. Further, extending the current study to include fMRI would be particularly useful for determining whether brain activity is correlated with guided decision-making after instructing participants to maintain their emotional experience.

The current study provides some evidence linking deficits in generating and maintaining mental representations of value to abnormalities in decision-making in SCZ. According the literature on reward processing, there are several other potential mechanisms linking reward and emotional processing to behavior, such as hedonics (i.e., liking), reward prediction (i.e., wanting), uncertainty driven exploration, and effort-cost computation (see Barch & Dowd, 2010 and Strauss, Waltz, & Gold, 2014 for review). Thus, future work reporting on multiple aspects of reward processing in the same sample is important given likely interactions between these reward processes. Deficits in maintaining representations of value may affect these multiple aspects of reward processing, and may even reflect a common mechanism that underlies motivational impairment in SCZ. For example, as suggested by Strauss et al. (2014), deficits in value representations may contribute to deficits in computing whether goal-directed activities are worth the effort needed to engage in them and making the decision to exploit actions that have led to prior rewards or to explore new actions. Therefore, it will be critical to examine the interaction of these mechanisms. Additionally, future studies should examine whether deficits on laboratory paradigms assessing value representations are related to ecologically meaningful problems with motivation. Experience sampling methods may be ideal for examining engagement in goal-directed behavior in the daily lives of people with and without SCZ.

Another interesting potential venue for future studies is to consider the time course of emotional responding using social stimuli to better understand the nature of social deficits in SCZ. Social anhedonia is a hallmark feature of SCZ (Meehl, 1962), is a key negative symptom (Blanchard and Cohen, 2006; Horan et al., 2006; Blanchard et al., 2011), and contributes to poor social functioning in SCZ (Meehl, 1962; Blanchard et al., 1998). Furthermore, impaired social functioning impacts quality of life (Penn, Corrigan, Bentall, Racenstein, & Newman, 1997) and predicts poor outcome in SCZ including relapse, poor illness course, and unemployment (Perlick, Stastny, Mattis, & Teresi, 1992; Sullivan, Marder, Liberman, Donahoe, & Mintz, 1990; Tien & Eaton, 1992); thus extending the current study to include social stimuli could potentially clarify the psychological and neural underpinnings of affective abnormalities related to social information.

The ultimate goal of this research is to understand the neural underpinnings of emotional processing that affect goal-directed behavior in SCZ. New avenues for remediating emotional deficits in SCZ may arise if future work verifies emotional maintenance deficits in SCZ. Though speculative at this point, future research may consider developing treatments in which patients maintain and reflect upon their emotional experience or complete computerized exercises that train them to maintain emotional responses over increasingly longer periods of time. Finally, in the current study, SCZ reported normal emotional experience to positive stimuli. This can be regarded as a strength to build upon in psychosocial interventions to address negative symptoms; for example, having patients attend to feelings of pleasure to encourage them to engage in goal-directed activities.

Tables

Table 1

Demographic and Clinical Characteristics

	SCZ (n=27)	CN (n=23)	Test Statistic	*p*-value
	M (SD)	*M (SD)*		
Age	39.04 (12.16)	40.13 (10.68)	*F* = 0.11	0.739
Education (years)	13.41 (1.78)	15.83 (2.04)	*F* = 20.06	<0.001
Parent education (years)	14.31 (2.70)	14.98 (2.83)	*F* = 0.72	0.401
% Male	75.07%	73.91%	χ^2 = 0.00	0.990
Race (%)			χ^2 = 2.06	0.724
Caucasian	59.3%	56.5%	--	--
African-American	33.3%	34.8%	--	--
American Indian or Alaskan Native	3.7%	0.0%	--	--
Asian	0%	4.3%	--	--
Other	3.7%	4.3%	--	--
Working memory*	36.81 (9.90)	50.00 (9.82)	*F* = 21.66	<0.001
CAINS-MAP total	15.29 (7.85)	--	--	--
CAINS-EXP total	6.21 (3.93)	--	--	--
BPRS total	37.96 (9.92)	--	--	--
BPRS positive	2.31 (1.29)	--	--	--
BPRS negative	2.00 (0.93)	--	--	--
BPRS disorganized	1.72 (0.74)	--	--	--
LOF total	19.23 (6.53)	--	--	--

LOF social	4.58 (2.49)	--	--	--
LOF work	2.35 (2.84)	--	--	--

Note. * = 1 participant missing MCCB working memory domain scores.

Table 2

SCZ Correlations Between Emotional Maintenance Accuracy and LPP Amplitude Difference Scores

Measure	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1500 ms							
1. Emo Accuracy	--						
2. 3000–3500 ms	-0.03	--					
3. 3500–4000 ms	-0.09	0.78**	--				
4. 4000–4500 ms	0.02	0.62*	0.76**	--			
3000 ms							
1. Emo Accuracy	--						
2. 3000–3500 ms	-0.03	--					
3. 3500–4000 ms	0.21	0.87**	--				
4. 4000–4500 ms	0.23	0.69**	0.84**	--			
2. 4500–5000 ms	0.08	0.58*	0.69**	0.86**	--		
6. 5000–5500 ms	0.20	0.52*	0.48*	0.74**	0.77**	--	
7. 5500–6000 ms	0.08	0.50*	0.51*	0.65**	0.82**	0.77**	--

Note. Emo Accuracy = Emotion maintenance accuracy
**$p < 0.001$. *$p < 0.01$.

Table 3

CN Correlations Between Emotional Maintenance Accuracy and LPP Amplitude Difference Scores

Measure	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1500 ms							
1. Emo Accuracy	--						
2. 3000–3500 ms	0.05	--					
3. 3500–4000 ms	-0.10	0.80**	--				
4. 4000–4500 ms	-0.17	0.66**	0.89**	--			
3000 ms							
1. Emo Accuracy	--						
2. 3000–3500 ms	-0.17	--					
3. 3500–4000 ms	0.08	0.89**	--				
4. 4000–4500 ms	0.12	0.83**	0.93**	--			
2. 4500–5000 ms	0.03	0.79**	0.87**	0.95**	--		
6. 5000–5500 ms	0.12	0.68**	0.80**	0.90**	0.94**	--	
7. 5500–6000 ms	0.13	0.69**	0.79**	0.87**	0.87**	0.94**	--

Note. Emo Accuracy = Emotion maintenance accuracy
**p < 0.001. *p < 0.01.

Table 4

Regression Models Predicting SCZ Emotion Maintenance Accuracy During the 1500 ms Maintenance Period from LPP Amplitude Difference Scores

	b	SE-	β	R^2	*F*
Step 1				.03	0.21
	0.67	0.03			
	0.01	0.02	.09		
	-	0.03	-		
	0.01	0.02	.22		
Step 2				.03	0.31
	0.67	0.03			
	-	0.02	-		
	0.01	0.02	.22		
Step 3				.01	0.68
	0.67	0.03			
	-	0.01	-		
Step 4					
	0.67				

Table 5

Regression Models Predicting CN Emotion Maintenance Accuracy During the 1500 ms Maintenance Period from LPP Amplitude Difference Scores

	b	SE-	β	R^2	*F*
Step 1				.07	0.51
	0.72	0.03			
	0.01	0.01	.30		
	-	0.02	-		
	-0.01	0.01	-		
Step 2				.07	0.80
	0.72	0.03			
	0.01	0.01	.28		
	-0.01	0.01	-		
Step 3				.03	0.61
	0.73	0.03			
	-0.01	0.01	-		
Step 4					
	0.74	0.02			

Table 6

Regression Models Predicting SCZ Emotion Maintenance Accuracy During the 3000 ms Maintenance Period from LPP Amplitude Difference Scores

	b	SE-	β	R^2	*F*
Step 1				.45	2.56
	0.70	0.02			
	-0.05	0.02	-		
	0.06	0.02	1.73**		
	-0.01	0.02	-0.27		
	-0.03	0.02	-0.79		
	0.03	0.01	0.82*		
	0.003	0.01	0.08		
Step 2				.45	3.21*
	0.70	0.02			
	-0.05	0.02	-		
	0.06	0.02	1.74**		
	-0.01	0.02	-0.31		
	-0.03	0.01	-0.73		
	0.03	0.01	0.85*		
Step 3				.44	4.06*
	0.70	0.02			
	-0.05	0.01	-		
	0.05	0.01	1.50**		
	-0.03	0.01	-0.80*		
	0.03	0.01	0.74*		

Note. ** $p < 0.01$; * $p < 0.05$

Table 7

Regression Models Predicting CN Emotion Maintenance Accuracy During the 3000 ms Maintenance Period from LPP Amplitude Difference Scores

	b	SE-	β	R^2	*F*
Step 1				.60	1.52
	0.76	0.03			
	-0.03	0.01	-		
	0.02	0.02	.766		
	0.03	0.02	1.052		
	-0.03	0.03	-		
	0.01	0.03	.305		
	-	0.02	-.045		
Step 2				.60	1.94
	0.76	0.03			
	-0.03	0.01	-		
	0.02	0.02	.768		
	0.03	0.02	1.033		
	-0.03	0.02	-.988		
	0.01	0.02	.253		
Step 3				.60	2.49
	0.76	0.03			
	-0.03	0.01	-		
	0.03	0.02	.794		
	0.03	0.02	1.067		
	-0.02	0.02	-.753		
Step 4					
	0.76	0.03		.55	2.79
	-0.04	0.01	-		
	0.03	0.02	.891		
	0.01	0.01	.280		
Step 5					
	0.75	0.02		.54	4.18*
	-0.04	0.01	-		
	0.04	0.01	1.140		

Note. ** p< 0.01; * p< 0.05

Table 8

SCZ Correlations Between Emotional Maintenance Accuracy and CAINS-MAP

Measure	*1*	*2*	*3*	*4*
1500 ms				
1. CAINS MAP	--			
2. Positive	-0.04	--		
3. Negative	-0.42*	0.48*	--	
4. Neutral	-0.43*	0.46*	0.48*	--
3000 ms				
1. CAINS MAP	--			
2. Positive	-0.21	--		
3. Negative	-0.42*	0.45*	--	
4. Neutral	-0.24	0.66**	0.46*	--

Note. CAINS MAP = CAINS Motivation and Pleasure scale total. Positive = Positive emotion maintenance accuracy; Negative = negative emotion maintenance accuracy; Neutral = neutral emotion maintenance accuracy.
**$p < 0.001$. *$p < 0.05$.

Table 9

Regression Models Predicting SCZ Emotion Maintenance Accuracy During the 1500 ms Maintenance Period from CAINS MAP Scores

	b	SE-*b*	β	R^2	*F*
Step 1				.32	3.24*
	35.82	8.58			
	16.27	10.57	.33		
	-	13.37	-.39		
	-	10.85	-.39		
Step 2				.24	3.46*
	38.13	8.71			
	-	12.99	-.28		
	-	10.67	-.29		
Step 3				.18	5.09*
	31.81	7.33			
	-	9.48	-		

Note. Positive = Positive emotion maintenance accuracy; Negative = negative emotion maintenance accuracy; Neutral = neutral emotion maintenance accuracy.
*$p<0.05$.

Table 10

Regression Models Predicting SCZ Emotion Maintenance Accuracy During the 3000 ms Maintenance Period from CAINS MAP Scores

	b	SE-*b*	β	R^2	*F*
Step 1				.18	1.57
	34.35	9.91			
	1.52	17.10	.02		
	-	13.59	-.40		
	-3.20	11.45	-.08		
Step 2				.18	2.46
	34.70	8.88			
	-	12.93	-.40		
	-2.62	9.15	-.06		
Step 3				.18	5.03*
	33.95	8.31			
	-	11.28	-		

Note. Positive = Positive emotion maintenance accuracy; Negative = negative emotion maintenance accuracy; Neutral = neutral emotion maintenance accuracy
*p<0.05.

Table 11

SCZ Correlations Between the LPP Persistence Difference Scores and CAINS-MAP

Measure	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1500 ms							
1. CAINS MAP	--						
2. 3000–3500 ms	0.32	--					
3. 3500–4000 ms	0.23	0.78**	--				
4. 4000–4500 ms	0.09	0.61*	0.76**	--			
3000 ms							
1. CAINS-MAP	--						
2. 3000–3500 ms	-0.11	--					
3. 3500–4000 ms	-0.10	0.87**	--				
4. 4000–4500 ms	-0.19	0.68*	0.85**	--			
2. 4500–5000 ms	-0.05	0.57*	0.69*	0.86**	--		
6. 5000–5500 ms	-0.10	0.53*	0.50*	0.74**	0.77**	--	
7. 5500–6000 ms	-0.06	0.50*	0.51**	0.65**	0.82**	0.77**	--

Note. CAINS MAP = CAINS Motivation and Pleasure scale total.
***p*< 0.001. **p*< 0.01.

Table 12

Regression Models Predicting SCZ LPP Persistence During the 1500 ms Maintenance Period from CAINS MAP Scores

	b	SE-	β	R^2	F
Step 1				.12	0.84
	13.49	2.04			
	1.43	1.33	.38		
	.33	1.64	.09		
	-.64	1.03	-		
Step 2				.12	1.30
	13.53	1.98			
	1.59	1.02	.43		
	-.522	.83	-		
Step 3				.10	2.27
	13.76	1.92			
	1.20	.79	.32		
Step 4					
	15.09	1.76			

Table 13

Regression Models Predicting SCZ LPP Persistence During the 3000 ms Maintenance Period from CAINS MAP Scores

	b	SE-	β	R^2	*F*
Step 1				.15	0.50
	14.88	1.83			
	-1.11	1.43	-.45		
	2.07	1.96	.93		
	-3.00	1.88	-		
	1.41	1.45	.56		
	0.86	1.18	.37		
	-0.58	1.21	-.21		
Step 2				.14	0.58
	14.93	1.78			
	-1.13	1.40	-.46		
	2.00	1.91	.90		
	-2.76	1.77	-		
	1.00	1.15	.40		
	0.63	1.06	.28		
Step 3				.12	0.65
	14.73	1.72			
	-0.65	1.13	-.27		
	1.27	1.44	.57		
	-2.13	1.39	-.92		
	1.24	1.06	.49		
Step 4					
	14.79	1.69		.11	0.78
	0.63	0.90	.28		
	-1.92	1.32	-.83		
	1.16	1.04	.46		
Step 5					
	15.18	1.57		.08	0.96
	-1.28	0.94	-.55		
	1.06	1.01	.42		
Step 6					
	15.16	1.58		.04	0.82
	-0.44	0.49	-.19		
Step 7					
	15.167	1.57			

Table 14

SCZ Correlations Between Emotional Maintenance Accuracy and LOF Total

Measure	*1*	*2*	*3*	*4*
1500 ms				
1. LOF Total	--			
2. Positive	0.09	--		
3. Negative	0.25	0.61**	--	
4. Neutral	0.47*	0.45*	0.49*	--
3000 ms				
1. LOF Total	--			
2. Positive	0.16	--		
3. Negative	0.22	0.50*	--	
4. Neutral	0.29	0.62**	0.46*	--

Note. LOF = Level of Function scale.
**$p < 0.001$. *$p < 0.01$.

Table 15

Regression Models Predicting SCZ Emotion Maintenance Accuracy Scores for the 1500 ms Maintenance Period from LOF Total Scores

	b	SE-*b*	β	R^2	*F*
Step 1				.26	2.53
	4.77	7.39			
	-	10.58	-.23		
	7.71	12.66	.15		
	21.02	8.96	.51*		
Step 2				.24	3.71*
	6.53	6.70			
	-7.04	9.03	-.16		
	22.63	8.44	.55*		
Step 3				.22	6.93*
	5.87		.49		
	7.47	7.47	.47*		

Note. ** p< 0.01; *p<0.05

Table 16

Regression Models Predicting SCZ Emotion Maintenance Accuracy Scores for the 3000 ms Maintenance Period from CAINS MAP Scores

	b	SE-*b*	β	R^2	*F*
Step 1				.09	0.74
	9.34	8.53			
	-3.38	14.75	-		
	5.82	11.78	.12		
	10.21	10.11	.27		
Step 2				.09	1.13
	8.61	7.73			
	5.01	11.01	.10		
	9.04	8.53	.24		
Step 3				.08	2.13
	10.84	5.89			
	10.84	7.43	.29		
Step 4					
	19.23	1.28			

Table 17

SCZ Correlations between the LPP Persistence Difference Scores and LOF Total Scores

Measure	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1500 ms							
1. LOF Total	--						
2. 3000–3500 ms	-.017	--					
3. 3500–4000 ms	-0.23	0.79**	--				
4. 4000–4500 ms	-0.13	0.64**	0.77**	--			
3000 ms							
1. CAINS-MAP	--						
2. 3000–3500 ms	0.14	--					
3. 3500–4000 ms	0.07	0.87**	--				
4. 4000–4500 ms	0.03	0.69**	0.84**	--			
2. 4500–5000 ms	-0.04	0.59*	0.69**	0.87**	--		
6. 5000–5500 ms	0.01	0.53*	0.48*	0.76**	0.76**	--	
7. 5500–6000 ms	0.07	0.52*	0.51*	0.68**	0.81**	0.76**	--

Note. LOF = Level of Function scale.
**p< 0.001. *p< 0.01.

Table 18

Regression Models Predicting SCZ Emotion Maintenance Accuracy Scores for the 1500 ms Maintenance Period from LOF Total Scores

	b	SE-	β	R^2	*F*
Step 1				.06	0.40
	20.37	1.64			
	0.10	1.14	.03		
	-1.08	1.36	-		
	0.28	0.86	.12		
Step 2				.06	0.63
	20.41	1.54			
	-1.00	1.06	-		
	0.29	.84	.12		
Step 3				.05	1.19
	20.33	1.48			
	-0.72	0.66	-		
Step 4					
	19.74	1.39			

Table 19

Regression Models Predicting SCZ Emotion Maintenance Accuracy Scores for the 3000 ms Maintenance Period from LOF Total Scores

	b	SE-	β	R^2	*F*
Step 1				.08	0.28
	19.40	1.52			
	0.85	1.23	.40		
	-0.77	1.67	-		
	1.00	1.64	.51		
	-1.14	1.27	-		
	-0.52	1.05	-		
	0.81	1.07	.33		
Step 2				.07	0.30
	19.35	1.49			
	0.37	0.65	.18		
	0.43	1.06	.22		
	-1.15	1.25	-		
	-0.21	0.79	-		
	0.80	1.04	.33		
Step 3				.07	0.38
	19.43	1.43			
	0.38	0.63	.18		
	0.33	0.96	.17		
	-1.15	1.22	-		
	0.68	0.92	.28		
Step 4				.06	0.48
	19.37	1.39			
	0.48	0.55	.23		
	-0.85	0.84	-		
	0.63	0.89	.26		
Step 5				.04	0.48
	19.26	1.36			
	0.52	0.54	.25		
	-0.41	0.57	-		
Step 6				.02	0.44
	19.32	1.35			
	0.29	0.43	.14		
Step 7					
	19.48	1.31			

Figures

Figure 1. Emotion and brightness rating task. After both maintenance tasks were completed participants rated their in-the-moment experience of emotion to images on emotion intensity, and their in-the-moment brightness experience to the brightness images, all using a visual analog scale. Using a gamepad, made their selection along the continuum for their experience rating. This figure was adapted from Gard et al., 2011.

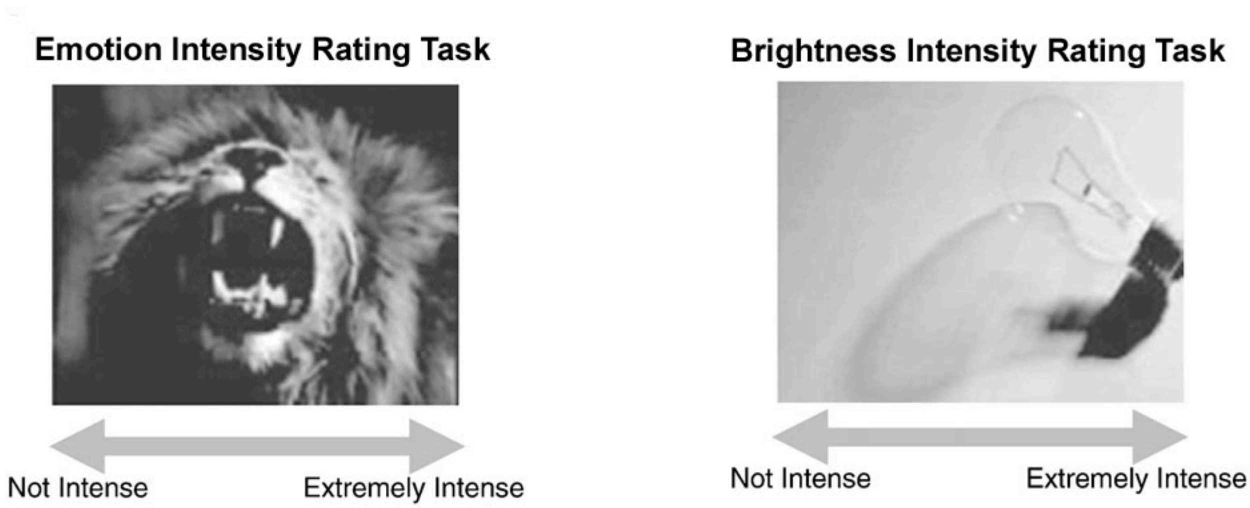


Figure 2. Emotional intensity maintenance task and brightness intensity maintenance task. For the emotion maintenance task a positive, negative, or neutral target picture was viewed for 3 s and the experience of emotional intensity was maintained over a 1.5 s or 3 s delay. A separate probe picture was viewed for 3 s. After the images, participants indicated whether the probe was experienced as more or less emotionally intense than the target. Participants completed an analogous brightness maintenance task, which was identical except neutral images were viewed and the experience of brightness intensity was maintained over a 3 s delay. This figure was adapted from Gard et al., 2011 and Mikels et al., 2008.

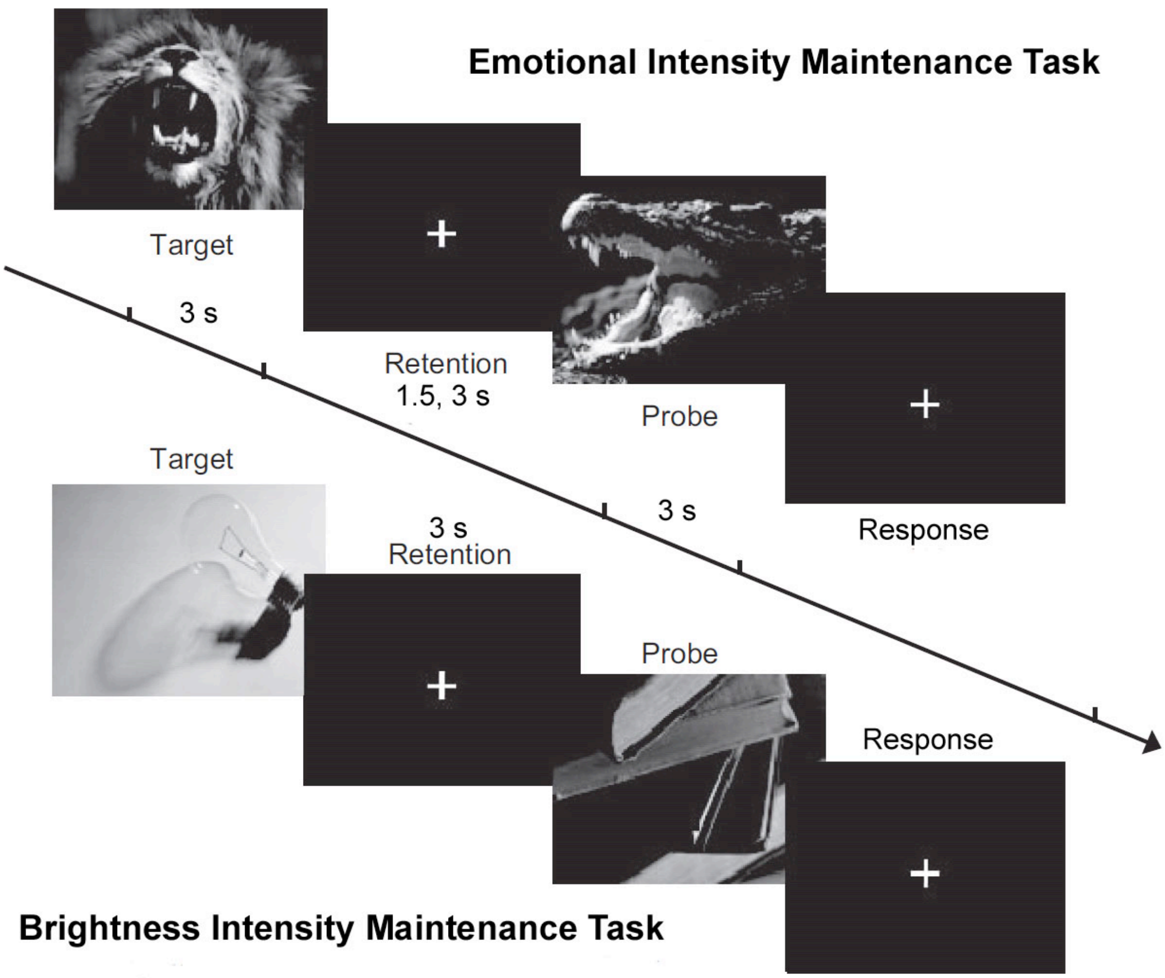


Figure 3. Group means and standard errors for brightness maintenance accuracy.

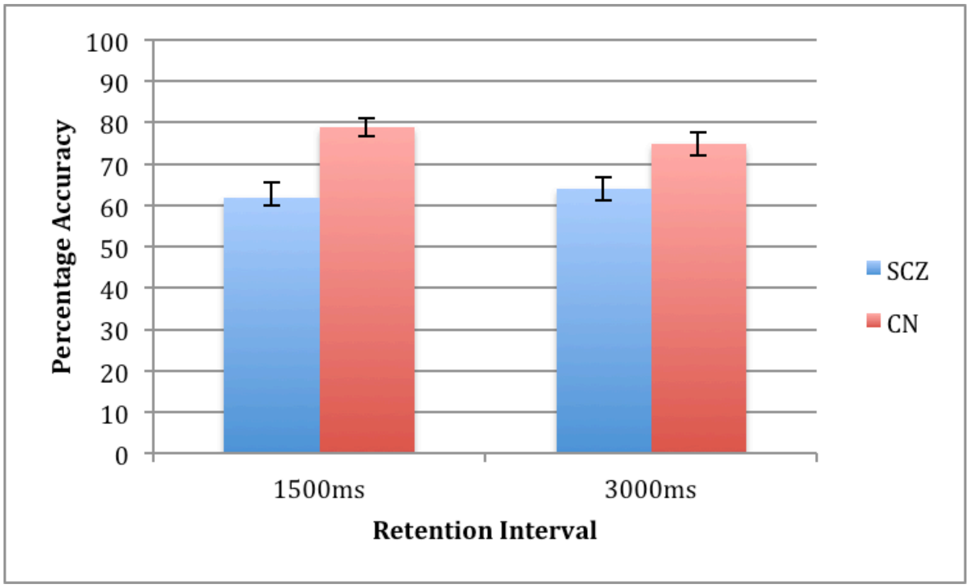


Figure 4. Group means and standard errors for brightness and intensity ratings.

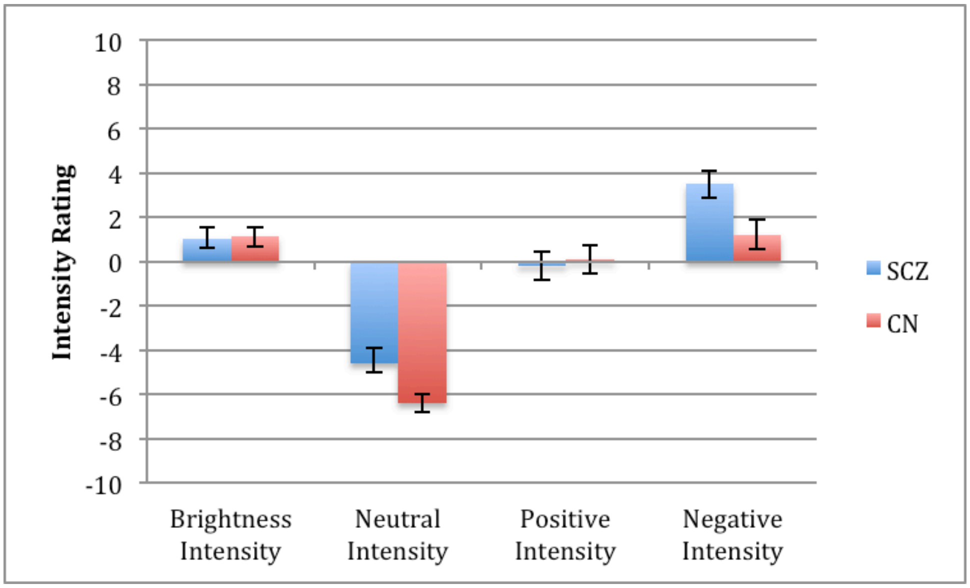


Figure 5. Group means and standard errors for preference judgment accuracy.

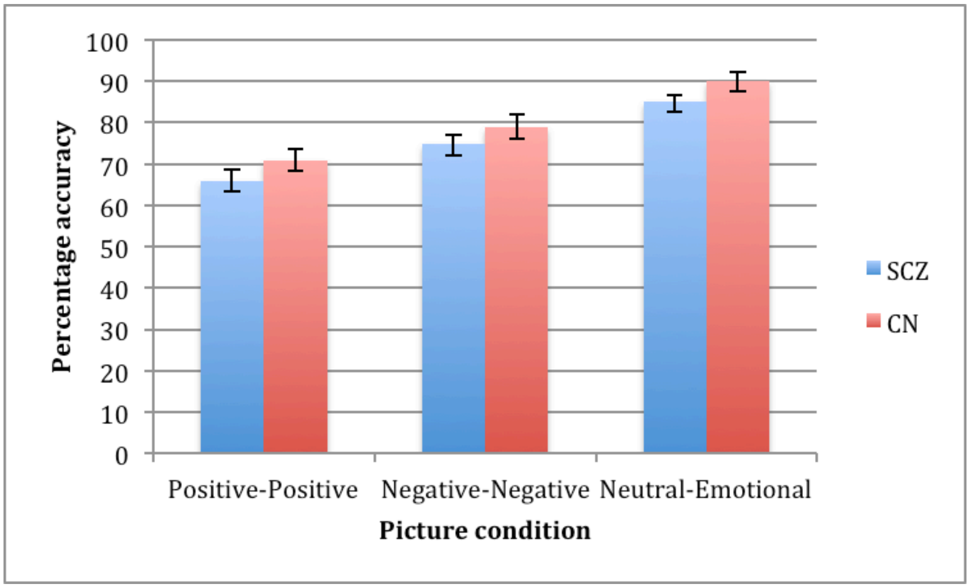
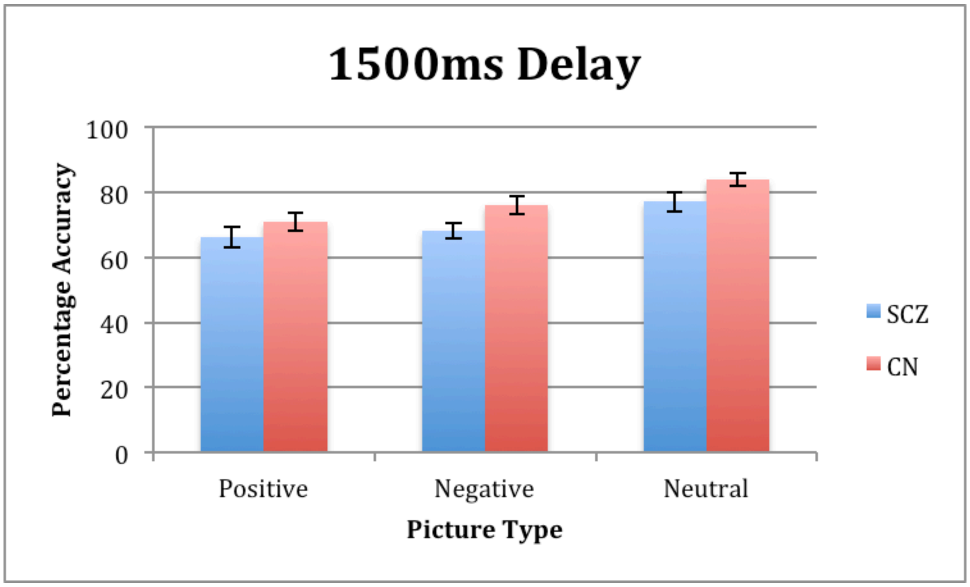


Figure 6. Group means and standard errors for emotional maintenance accuracy on 1500 ms and 3000 ms conditions.



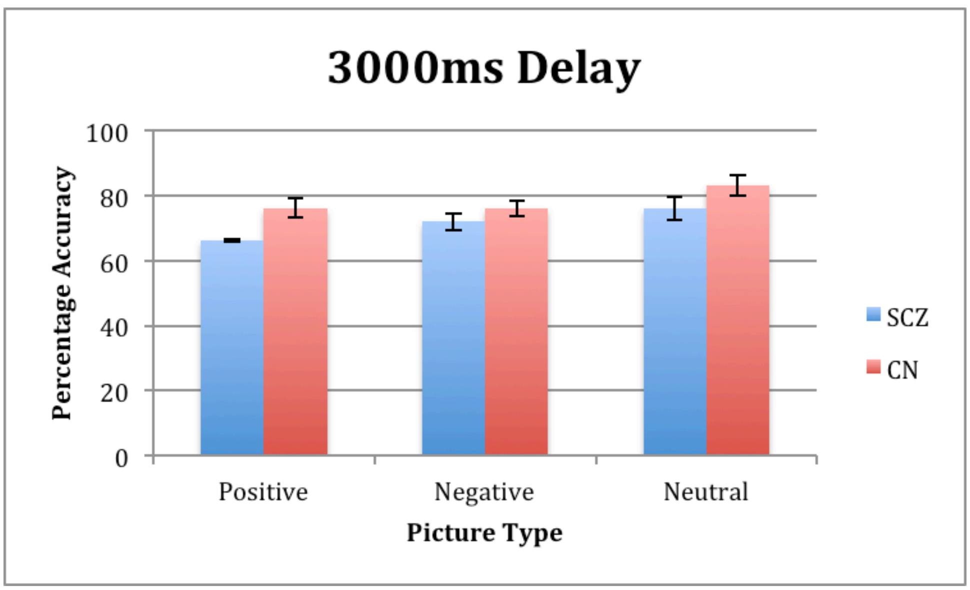


Figure 7. Overall waveforms for each valence at the three centro-parietal electrodes (Cz, CPz, and Pz) during picture presentation in the 1500 ms condition.

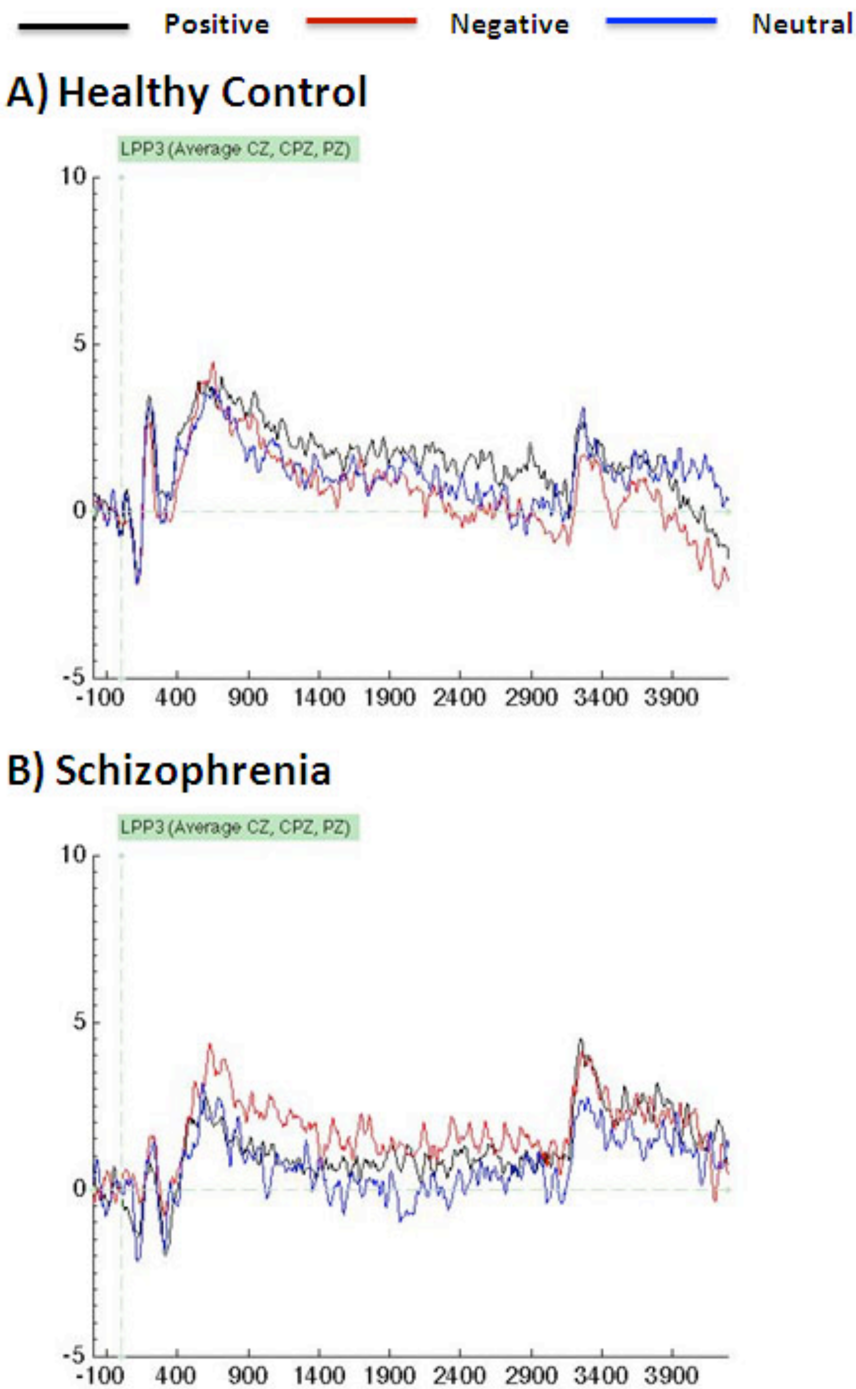


Figure 8. Overall waveforms at the three centro-parietal electrodes (Cz, CPz, and Pz) during picture presentation for the 3000 ms condition.

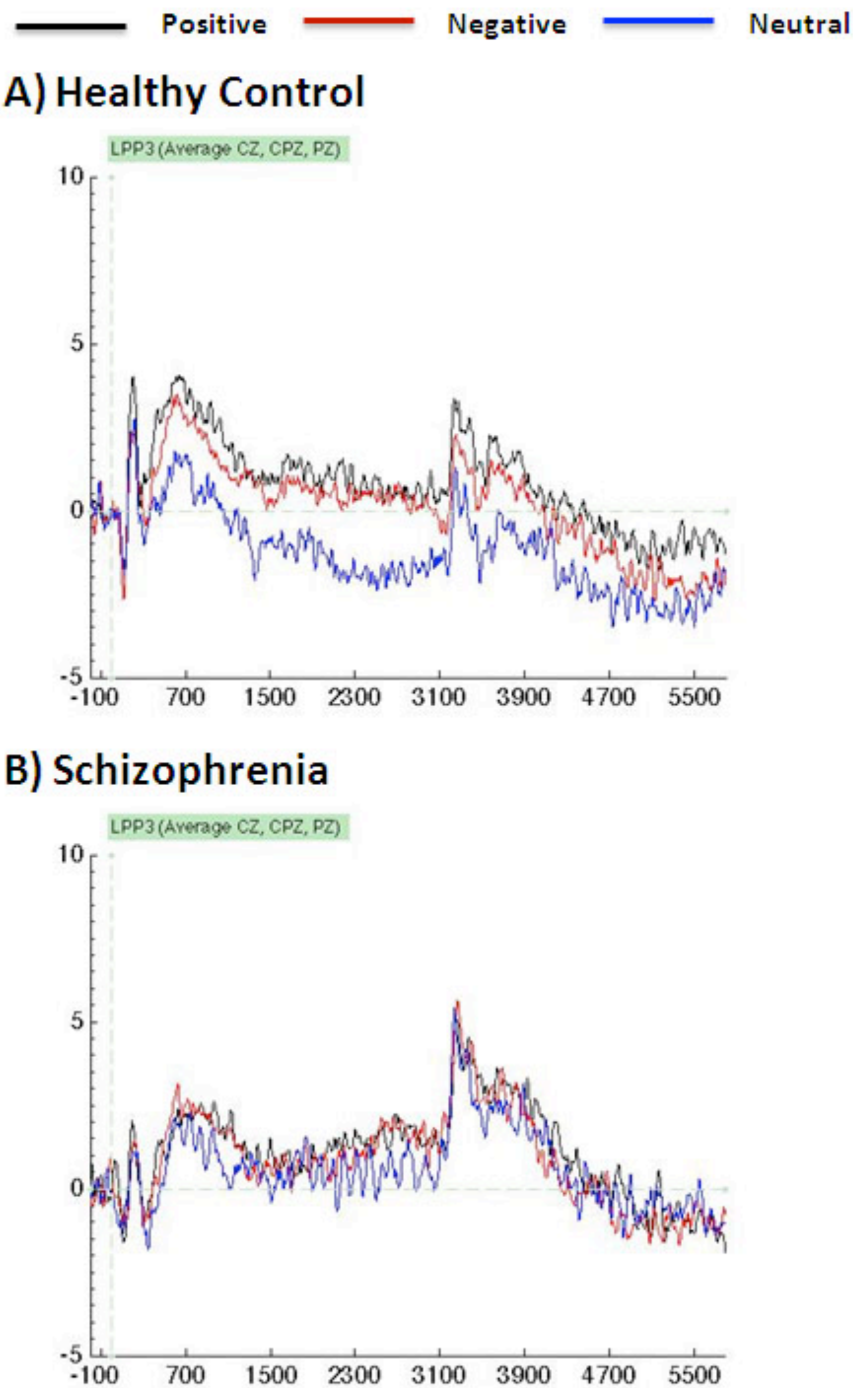


Figure 9. Mean LPP amplitude in Early, Middle, and Late windows per emotion condition in the 1500 ms delay condition. Error bars indicate the standard error.

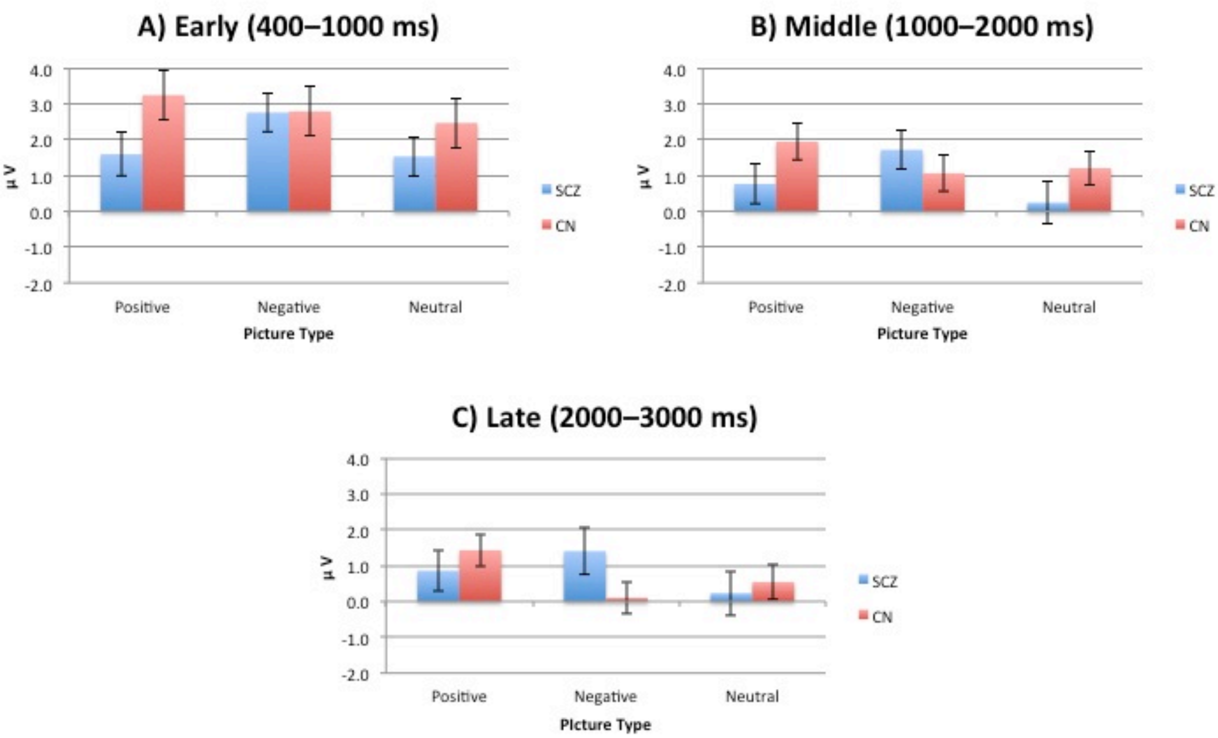


Figure 10. Mean LPP amplitude in Early, Middle, and Late Windows per emotion condition in the 3000 ms delay condition. Error bars indicate standard error.

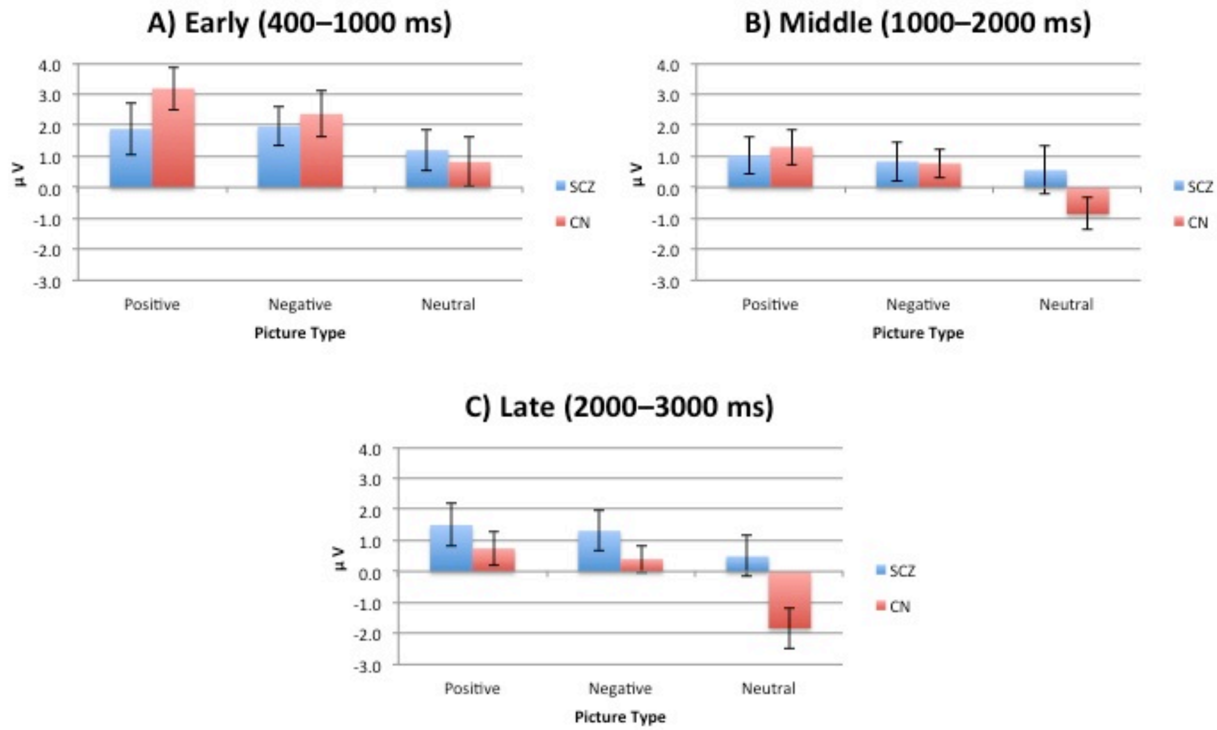


Figure 11. Mean LPP amplitude during picture offset per emotion condition in the 1500 ms condition. Error bars indicate standard error.

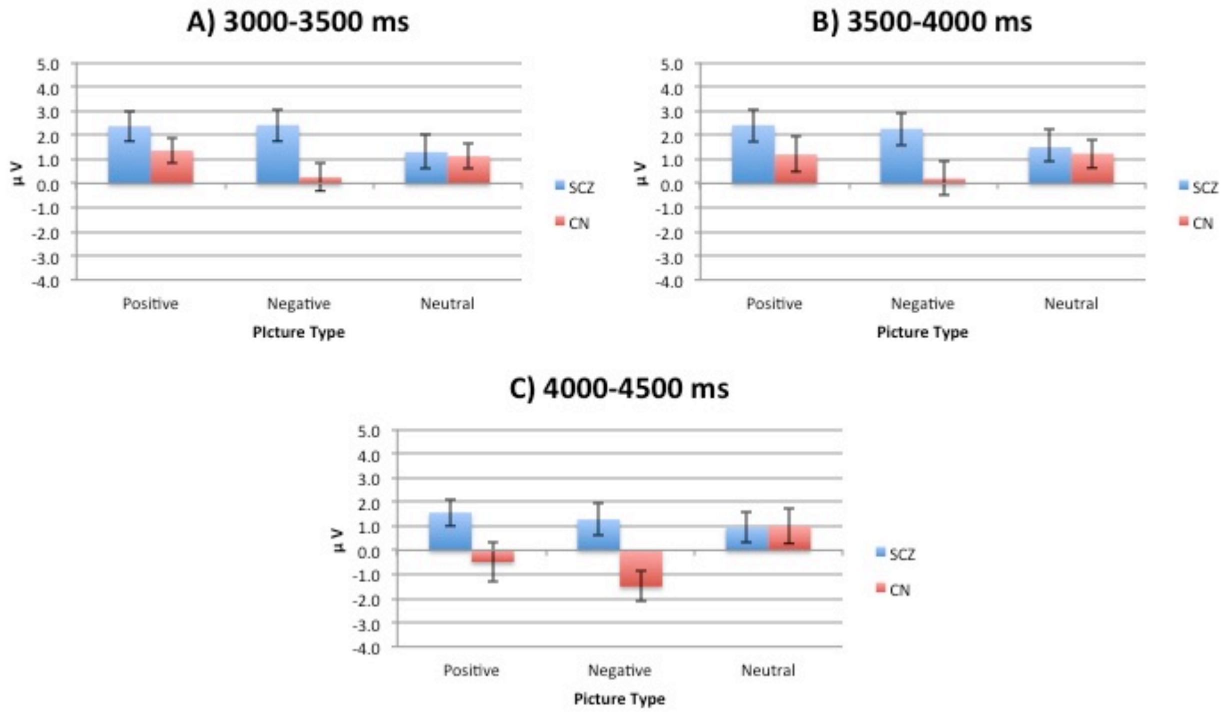


Figure 12. Mean LPP amplitude per time window during picture offset for the 3000 ms condition. Error bars indicate standard error.

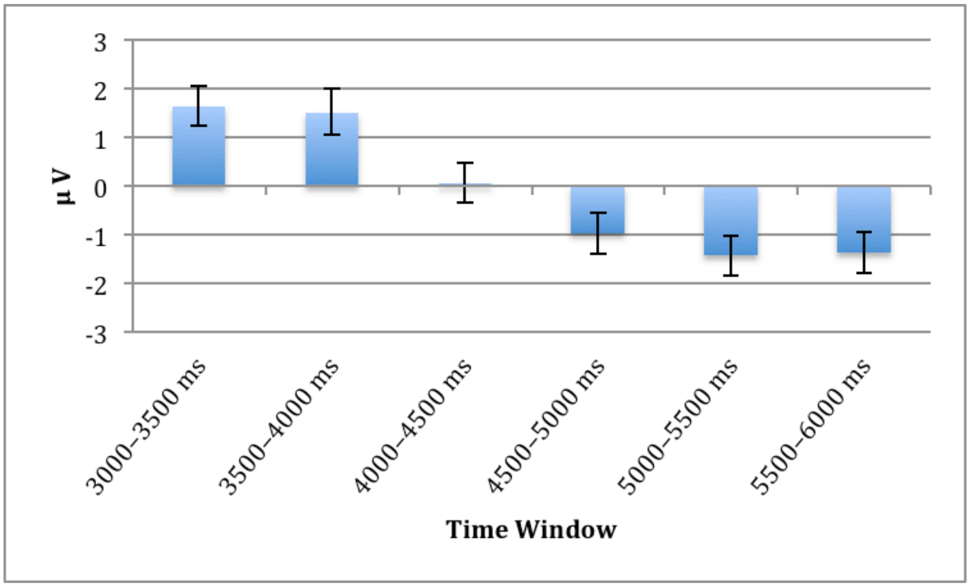


Figure 13. Mean LPP amplitude during picture offset per emotion condition in the 3000 ms condition. Error bars indicate standard error.

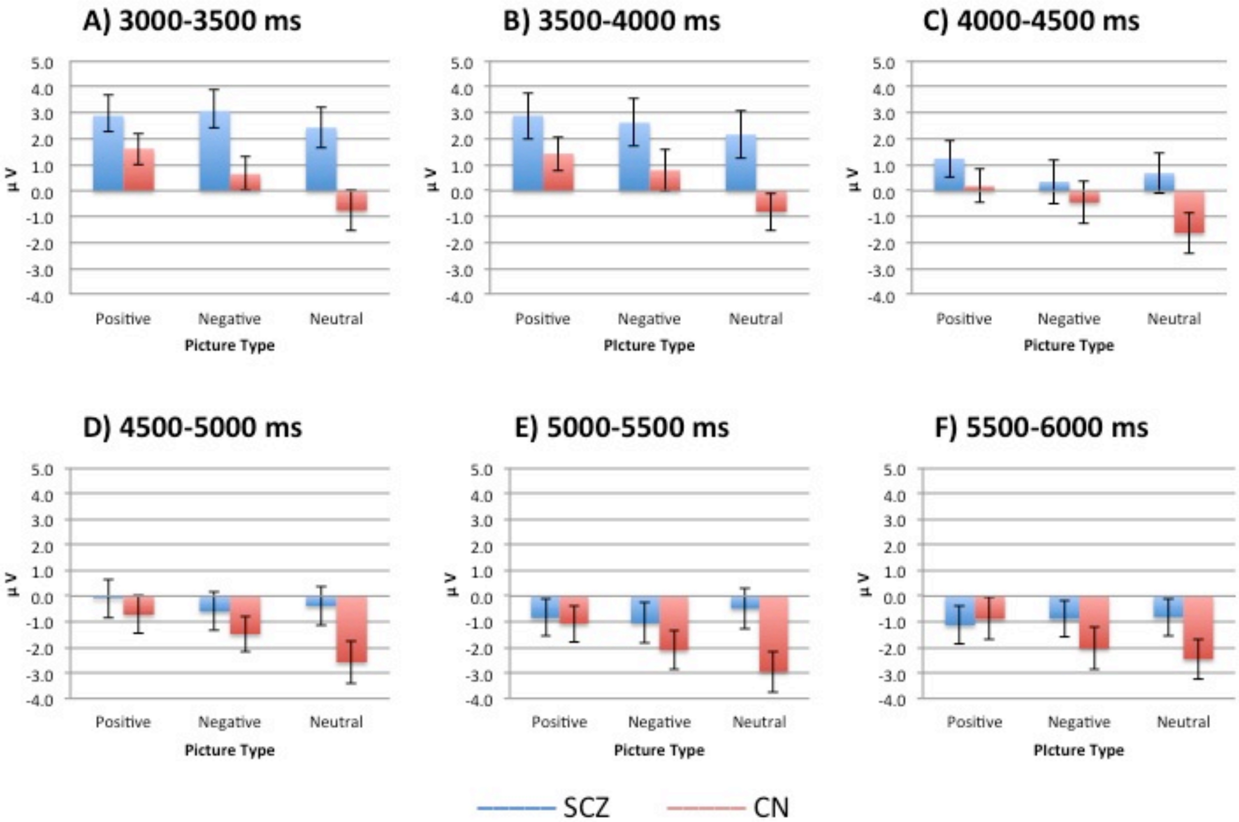


Figure 14. Overall waveforms at the three centro-parietal electrodes (Cz, CPz, and Pz) during probe presentation for the 1500 ms condition.

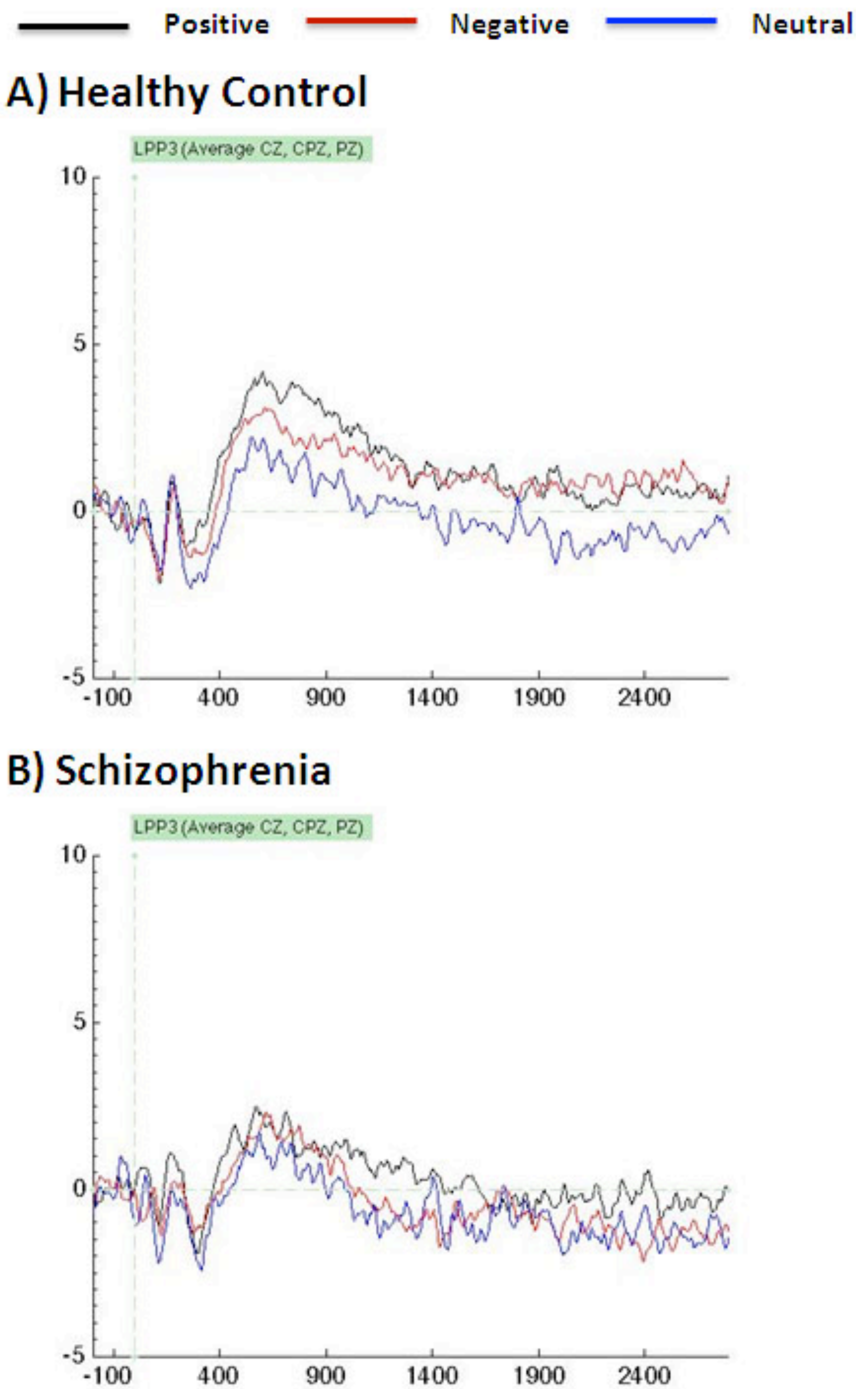


Figure 15. Overall waveforms at the three centro-parietal electrodes (Cz, CPz, and Pz) during probe presentation for the 3000 ms condition.

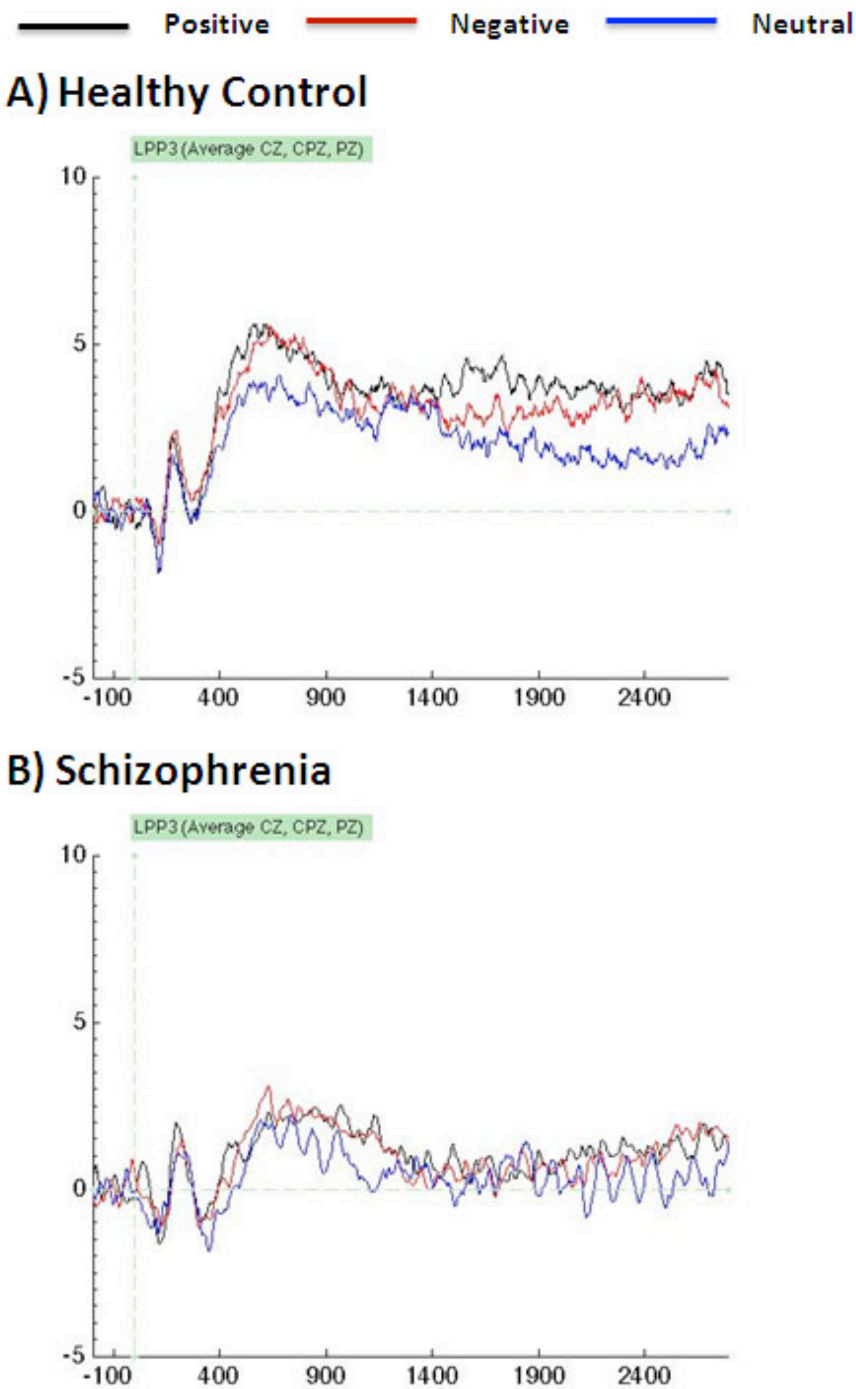


Figure 16. Mean LPP amplitude during probe picture presentation per emotion condition in the 1500 ms condition. Error bars indicate standard error.

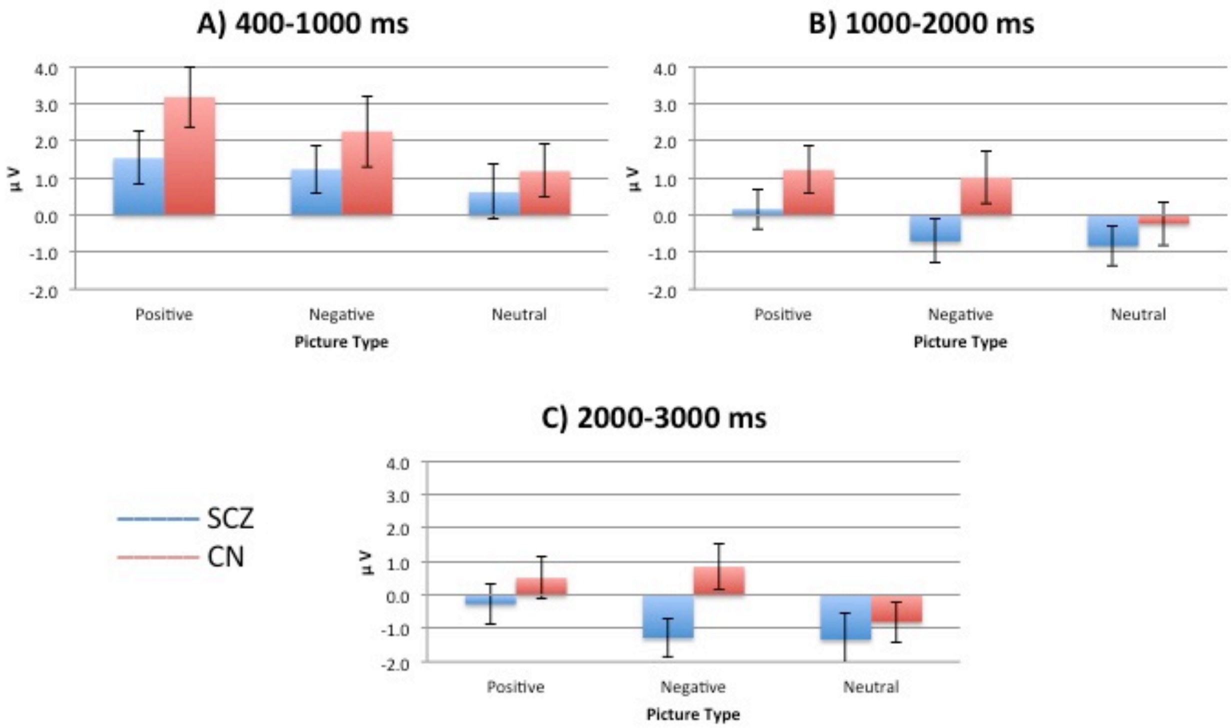
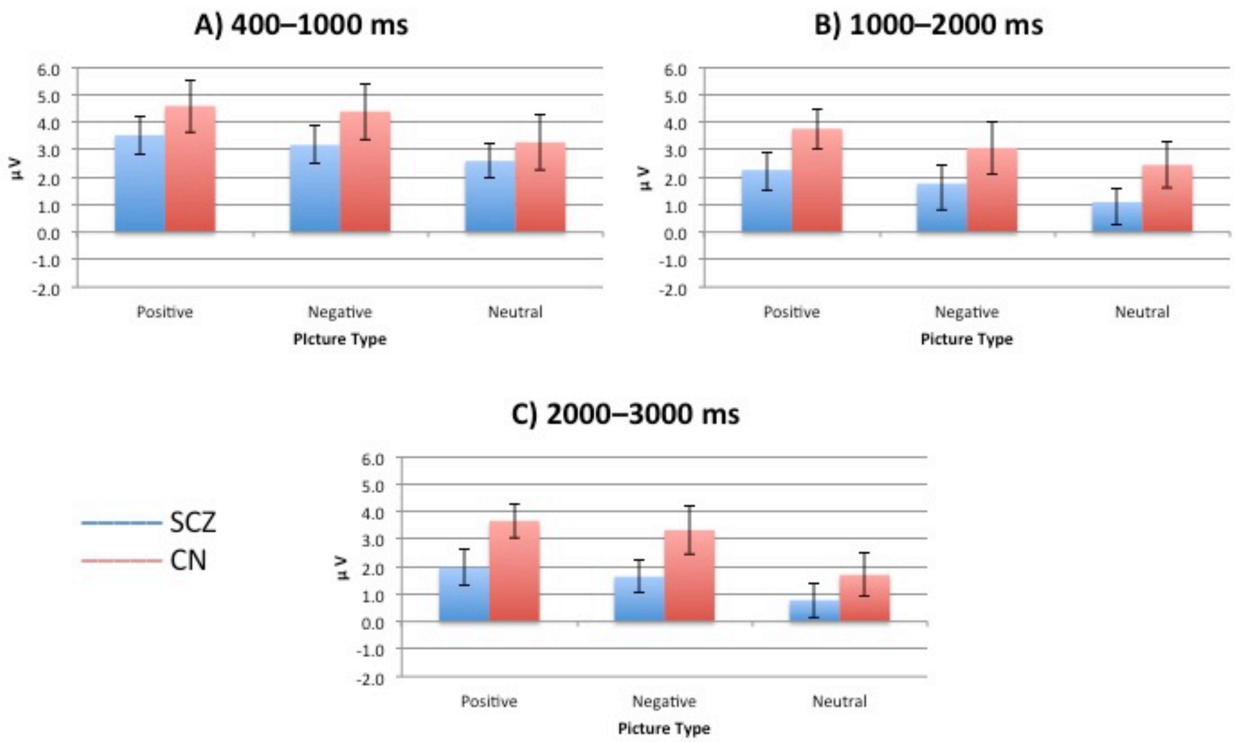


Figure 17. Mean LPP amplitude during probe picture presentation per emotion condition in the 3000 ms condition. Error bars indicate standard error.



Appendices

Appendix A: Emotional Maintenance Scores Based on Normative Ratings

Participants' comparisons on the emotion maintenance task were compared to normed ratings, and ratings significantly differed in some conditions. The table below shows paired-samples *t*-test statistics for emotional maintenance accuracy based on normative ratings and participant comparisons.

Condition	Schizophrenia N=27				Control N=23			
	Normative *M (SD)*	Participant Comparison *M (SD)*	*t*	*p*	Normative *M (SD)*	Participant Comparison *M (SD)*	*t*	*p*
1500ms								
Positive	0.58 (0.09)	0.66 (0.17)	-2.62	0.014	0.60 (0.10)	0.66 (0.17)	-3.20	0.004
Negative	0.64 (0.12)	0.68 (0.12)	-1.38	0.180	0.69 (0.11)	0.71 (0.13)	-2.03	0.054
Neutral	0.77 (0.20)	0.77 (0.16)	0.13	0.896	0.86 (0.10)	0.84 (0.11)	1.15	0.262
3000ms								
Positive	0.61 (0.11)	0.66 (0.12)	-1.66	0.109	0.62 (0.12)	0.76 (0.14)	-4.71	0.000
Negative	0.64 (0.13)	0.72 (0.13)	-2.90	0.008	0.67 (0.10)	0.76 (0.12)	-3.97	0.001
Neutral	0.78 (0.19)	0.76 (0.18)	.511	0.614	0.85 (0.12)	0.83 (0.15)	1.44	0.163

A 2 (Group) × 3 (Emotion) × 2 (Delay) repeated measures ANOVA revealed a significant within-subjects effect of Emotion, $F(2, 96) = 54.53$, $p < 0 .001$, partial $\eta^2 = 0.532$, indicating accuracy percentage scores were highest for neutral images (M = 81.5%, SD = 16.5%) compared to positive (M = 60.2%, SD = 10.6%) and negative (M = 66%, SD = 11.8%) images. There was no significant within-subjects effect of Delay, indicating that accuracy ratings were similar across delay intervals, $F(1, 48) = 0.259$, $p = 0.613$, partial $\eta^2 = 0.005$. There was a significant between-subjects effect of group, $F(1, 48) = 4.37$, $p = 0.042$, partial $\eta^2 = 0.083$, such that CN ($M = 71.6\%$, $SD = 11.1\%$) maintenance accuracy percentages were significantly higher than SCZ ($M = 66.9\%$, $SD = 13.9\%$). There were no significant interaction effects of Delay × Group ($F(1, 48) = 0.775$, $p = 0.383$, partial $\eta^2 = 0.02$), Emotion × Group ($F(2, 96) = 1.203$, $p = 0.304$, partial $\eta^2 = 0.02$), or Delay × Emotion ($F(2, 96) = 1.67$, $p = 0.194$, partial $\eta^2 = 0.03$), or Delay × Emotion × Group ($F(2, 96) = 0.028$, $p = 0.972$, partial $\eta^2 = 0.001$).

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