NEGATIVE AFFECT AND ILLICIT SUBSTANCE USE: THE MODERATING ROLE OF SELF-CONTROL

BY

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DISSERTATION

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ABSTRACT

Theories of substance use have historically focused on the role of negative affect and self-control, yet few studies have examined distinct aspects of self-control as moderators of link between negative affect and substance use in the participant's natural environment. The primary goal of this study was to examine whether different aspects of self-control (monitoring, adjusting, and persisting) measured using multiple methods (self-report, psychophysiological, behavior) moderate the relation between momentary negative affect and illicit substance use in a sample of current substance users with a history of substance use disorders. I predicted that the adjusting and persisting, but not the monitoring aspects of self-control would moderate the relation between momentary negative affect and substance use, such that negative affect would be positively related to substance use at low levels of monitoring and adjusting. Of the hypotheses, the best support was for the moderating role of the adjusting aspects of self-control in the negative affect - substance use relation. Specifically, negative affect was *positively* related to substance use at *low* levels of adjusting, but *negatively* related substance use at *high* levels of adjusting. My other hypotheses received limited support. This project makes several clear additions to the substance use literature that will inform future research. Most important is the finding that the adjusting aspects of self-control seem particularly important for understanding for whom negative affect may promote substance use. Persons who adjust well, in the face of errors, may be resilient to mood-dependent substance use. The null results for the other aspects of self-control (i.e., monitoring and persistence) may suggest that these aspects are less important than adjusting among current substance users.

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CHAPTER 1

INTRODUCTION

Despite decades of research, intervention, and prevention efforts, substance use and substance use disorders are still a public health issue. In the United States, approximately 24% of people smoke cigarettes regularly, 14% have engaged in binge drinking in the last 30 days, and 14% have used illicit substances in the last year (Frone, 2006; Miller et al., 2004; Rodu & Cole, 2009). Moreover, in any given year, 9% of the population experiences significant impairment and distress from their substance use, qualifying for a diagnosis of a substance use disorder (Grant et al., 2004). In addition to causing psychological distress and impairment in many users, substance use is also related to physical health problems including cardiovascular disease (Quershi et al., 2001; Roerecke & Rehm, 2010), stroke (Quershi et al., 2001; Shinton & Beevers 1989), cancer (Bagnardi, Blangiardo, Vecchia, & Corrao, 2001; Khuder, 2001), and early mortality (Castelnuovo et al., 2006; Degenhardt et al. 2010; Singleton, Degenhardt, Hall, & Zabransky, 2009). Substance use also is costly to society. It is estimated that cost of lost productivity, health care, treatment, and drug enforcement related to substance use is 559 billion dollars in the United States ($181 billion involving illegal substances; National Institute of Drug Abuse, 2008). Given the high prevalence and costs of substance use, research that helps elucidate factors that lead to a reduction in substance use is necessary in order to inform prevention and treatment efforts and ultimately reduce its impact.

Of the numerous candidate risk and maintenance factors for maladaptive substance use, the current study focuses on two psychological factors, state negative affect and trait self-control, for two reasons. First, these two factors have a prominent place in most psychological theories of substance use (Baker et al., 2004; Conger, 1956; Hull 1981; Koob, 2009; Sayette, 1993; Steele

& Josephs, 1990). Second, negative affect and self-control are targets of treatment in some empirically supported interventions for substance use (e.g., Bornovalova et al., 2012; Linehan et al., 2002; McCrady, 2008). Despite their ubiquitous presence in theoretical models, research has generally found that relations between negative affect, self-control, and substance use are complex (e.g., Kassel, Stroud, & Paronis, 2003; Wills, Walker, Mendoza, & Ainette, 2006), calling for more comprehensive models. Moreover, there are many methodological issues that make it difficult to adequately test the link between negative affect, self-control, and substance use. This study relies on self-report, psychophysiological, behavioral, and experience sampling methodologies to identify how different aspects of trait self-control moderate the relation between state negative affect substance use in illicit substance users.

Negative Affect and Substance Use

The earliest theories relating negative affect to substance use suggested that the negative affect associated with withdrawal was a motivation for continued substance use because substance use allows individuals to avoid unpleasant withdrawal symptoms (Lindesmith, 1947; Wikler, 1948). Building on this idea, Conger (1956) suggested that alcohol might be reinforcing because of its ability to reduce anxiety and fear even in the absence of withdrawal, motivating people to drink during states of general negative affect. Since these early theories, multiple lines of research support the proposed link between negative affect and substance use. First, individuals who use substances often report using them as a way to reduce negative affect (Patrick et al., 2011; Piasecki et al., 2010), although research suggests that the ability of substance use to reduce negative affect is complex (e.g., it may regulate some emotions better than others or only following certain situations; Moberg & Curtin, 2009; Perkins et al., 2010). Second, personality traits related to the tendency to experience negative affect (e.g., neuroticism) are associated with substance use and substance use disorders (Kotov et al., 2010; Settles et al., 2012). Third, state negative affect predicts future substance use for alcohol, nicotine, and marijuana (Armeli et al., 2007; Buckner et al., 2012; Conklin & Perkins, 2005; Kidorf & Lang, 1999; Shapiro et al., 2002; Swedsen et al., 2000; though see Shifman et al., 2002 for null results for nicotine). Fourth, research has shown that as substance dependence develops, the stress response becomes more similar to withdrawal symptoms, which are a cue for substance use (Fox et al., 2005; Sinha et al., 2000). In other words, it becomes difficult to distinguish between distress due to withdrawal and distress in general, which may increase the likelihood of substance use during all periods of negative affect. Finally, negative affect resulting from stress is often a trigger for relapse among those trying to remain abstinent (e.g., McKay et al., 2006; Shiffman et al., 1996; 2004).

It should also be noted that there are theories and empirical results that support a similar relation for positive affect and substance use (e.g., Baker et al., 2004). This research has focused on self-reported motives for use, contrasting enhancement motives (e.g., drinking to increase positive affect) and coping motives (drinking to reduce negative affect; Bonn-Miller, Zvolensky, & Bernstein, 2007; Patrick, Yeomans-Maldonado & Griffin, 2016; Ward, Kersh, & Shanks, 1997). Findings from this work indicate that coping motives are more predictive of substance use disorders than enhancement motives (Benschop et al., 2015; Carpenter & Hasin, 1999; van der pol, et al., 2013). The implication of these results is that the relation between positive affect and substance use may be more normative, whereas the relation between negative affect and substance use may reflect more problematic use. This is consistent with the broader literature showing that negative affect explains the most variance in mental disorders (e.g., Tackett et al., 2013; though see Stanton et al., 2016 for evidence of positive affect's role). Hence, I focus on negative affect, given evidence of its explanatory power for disordered substance use.

Though the link between negative affect and substance use has a body of support, there are a number of unresolved issues in the literature. One major issue is that most empirical studies in humans have largely focused on alcohol (e.g., Armeli et al., 2007; Swedsen et al., 2000) and tobacco (e.g., Conklin & Perkins, 2005; Shifman et al., 1996). Although a few recent studies have begun to establish this link for marijuana (e.g., Buckner et al., 2012; Buckner et al., 2013; Schrier et al., 2012), research lags behind in terms of other forms of illicit substances (e.g., cocaine, opioids), which are associated with greater negative consequences than marijuana. Studies have also often looked at the use of one substance in isolation, even though many people report regular use of several substances over time (e.g., Chan, Kelly, Carroll, & Williams, 2017; Kecojevic, Jun, Reisner, & Corliss, 2017). Moreover, previous research has found a more consistent link between negative affect and alcohol use than negative affect and tobacco use (e.g., Shiffman, 2009; Shiffman et al., 2002; Swedsen et al., 2000). Therefore, it is necessary to test whether such a relation holds for illicit drugs, rather than assuming that the results generalize to other substances.

The extant research is also inadequate because of limitations inherent in common methodologies used. Some research linking negative affect and substance use relies on retrospective reporting of affect and/or substance use (e.g., Bonn-Miller, Zvolensky, & Johnson, 2010; Bujarski & Ray, 2014; Patrick et al., 2011; Piasecki et al., 2010). Questionnaires used in these studies ask participants to report affect and substance use over a long time period (e.g., the number of times you used cocaine in the last month). Because of the cognitive demands of these items, participants generally rely on heuristics and their own lay-theories rather than mathematically aggregating behavior and/or affect over the time period, introducing bias into their responding (Gorin & Stone, 2001; Mayer, McCormick & Strong; Piasecki, Hufford, Solhan, & Trull, 2007; Robinson & Clore, 2002). Laboratory studies overcome this limitation; however, they involve highly artificial environments, calling into question the generalizability of findings from the laboratory. For instance, in contrast to experimental substance use studies, most substance use occurs in the presence of others and in the late hours of the night (e.g., Buckner, Crosby, Silgado, Wonderlich, & Schmidt, 2012; Hopper et al., 2006; Fairbairn & Sayette, 2014).

One method that circumvents both of these issues is ecological momentary assessment, which involves participants making multiple ratings in near real-time (e.g., "How do you feel right now?") in their natural environment with an electronic device (e.g., a cell phone; Shiffman, Stone, & Hufford, 2008). Despite the potential challenges of this methodology in substance using samples (e.g., concerns about compliance, reactance, or responding while intoxicated), ecological momentary assessment has been used in various aspects of substance use research for over two decades (e.g., Litt, Cooney, & Morse, 1998; Shiffman et al., 2002; Swendsen et al., 2000; for a review see Shiffman, 2008). Still, there is a dearth of studies using this methodology with participants engaged in illicit substance use other than marijuana (for examples of feasibility studies, see Epstein et al., 2009; Hopper et al., 2006). Finally, despite the theoretical work supporting a strong connection between negative affect and substance use, a review of ecological momentary assessment studies suggests that evidence for the links between negative affect and substance use are nuanced and mixed, with many studies finding a relation between negative affect and subsequent substance use (e.g., Buckner et al., 2012; Swendsen et al., 2000; Weinberger & McKee, 2012) and other studies reporting no relation (e.g., Bacon, & Thomas, 2013; Merrill, Wardell, & Read, 2009; Shiffman et al., 2002). This may suggest that there are important individual-level moderators that can explain for whom the experience of negative affect leads to substance use. Individual differences in self-control could be one factor that may moderate the relation between negative affect and illicit substance use.

Self-control as a Moderator of the Negative Affect – Substance Use Relationship

Self-control is often defined in one of two ways. Sometimes it is described as the ability to adjust one's own thoughts, feelings, and behaviors to pursue a goal (Baumeister & Vohs, 2003). Other times, self-control is defined as the ability to resist temptation and persist toward a goal (Hofmann et al., 2011).[1] Theories also posit that in order for self-control to occur, an individual must identify the need for self-control via monitoring progress toward goals (Carver & Scheier, 1998; Robinson et al., 2010). Noticing a discrepancy between the current state and the desired state signals the need for self-control. Thus, in the present project, self-control is defined as involving at least three components: a monitoring process and two operating processes, adjustment and persistence. Although self-control can be thought of as a state (i.e., "Did I adjust my behavior in a specific situation?"; Muraven & Slessareva, 2003; Tice, Baumeister, Shmueli & Muraven, 2007; Wan & Sternthal, 2008), individuals differ in their tendency to enact self-control across situations (i.e., "Do I tend to adjust my behavior when necessary?"; Hirsh & Inzlicht, 2010; Robinson, 2007; Tangey, Baumeister, & Boone, 2004; Weinberg, Riesel, & Hajcak, 2010). The current study focuses on the latter (dispositional self-

[1] Self-control is conceptually similar to constructs such as executive function (Miyake & Friedman, 2012), cognitive control (Robinson, Schmeichel, & Inzlicht, 2010), emotion regulation (Gross, 1998), and distress tolerance (Leyro, Zvolensk, Berstein, 2010). Although not the focus of the current studies, my view is that executive function and cognitive control are cognitive processes that allow for self-control to happen (i.e., executive functions are the cognitive building blocks of self-control). Emotion regulation is a higher order function that relies on both executive function and self-control (e.g., adjustment of behavior). Finally, distress tolerance is persisting during physical or psychological distress, meaning that it is a special case of persistence (Leyro et al., 2010).

control) because it represents a relatively stable vulnerability factor likely to play a role in the development and maintenance of maladaptive substance use across situations.

For self-control to happen in any given instance, it is necessary for the individual to notice the discrepancy between the goal state and current state (Carver & Scheier, 1998; Robinson et al., 2010). For example, an individual who wants to obtain a job, but is perhaps not currently engaged in any behaviors leading to that goal (e.g., sitting at home all day), may experience negative affect (Carver & Scheier, 1998; Higgins 1986). This negative affect increases the urge to use substances for a variety of reasons (e.g., they may have the expectation that substance use reduces negative affect; Smith, 1989). In order to reduce the negative affect and work toward the goal, the individual needs to notice the need for self-control. Once the need is detected, self-control can be implemented in two ways, which map onto the definitions above. One option is that the individual may decide to adjust their thoughts, feelings, or behaviors to be more in line with their current goals. That is, instead of staying at home, the individual can decide to complete and return job applications. The other option is for the individual to ignore temptation and persist toward the current goal. In this case, the individual may experience the urge to use substances, but resist this temptation knowing that it could affect the pursuit of the goal (e.g., they may not pass a drug test).

According to this model, self-control failure (in this case, using substances) in any given situation could occur for a number of reasons. If the individual does not notice the need for self-control, they will be unable to use it, suggesting that monitoring is necessary for self-control (Carver & Scheier, 1998). However, simply noting the need for self-control is insufficient. The individual must also engage in either adjustment or persistence successfully, in order to avoid engaging in behavior inconsistent with their goal. Moreover, successfully implementing self-control in any one situation may not be as important as an individual's tendency to successfully implement self-control across situations, suggesting that individual differences in self-control may be more important than state self-control for understanding maladaptive substance use.

Because monitoring is necessary but not sufficient for self-control, individual differences in the tendency to monitor are likely to have very little effect on the negative affect-substance use link. In contrast, individual differences in adjusting and persisting are likely to moderate this link. Specifically, for individuals who tend to adjust their behavior or persist in the face of temptation (versus those who do not), the link between state negative affect and substance use will be weaker. Such a model may have predictive power among substance users trying to remain abstinent as well as among those who are continuing to use substances. The abstinent person would need to implement self-control to avoid using substances as part of their abstinence goals, and the current users would need to implement self-control to avoid using substances in situations in which it would be highly counterproductive to the person's life goals (e.g., at work, to avoid incarceration). Thus, self-control is expected to moderate the negative affect-substance use relation among current users, and not only among those with abstinence goals.

Multi-method Assessment of the Different Aspects of Self-control

Individual differences in self-control can be assessed in a number of ways. There are a multitude of self-report scales that assess different aspects of self-control (e.g., Roth et al., 2005; Simons & Gaher, 2005; Tangney et al., 2004; Whiteside & Lynam, 2001). For example, the Behavior Rating Inventory of Executive Function (BRIEF; Roth et al., 2005) indexes a number of aspects of executive function and self-control. Based on a content analysis of the items, three of the nine subscales were deemed particularly relevant to the current investigation (task monitoring, shifting, and inhibition), as they map on to the above-named aspects of self-control, namely monitoring, adjusting, and persisting. The task monitoring subscale measures frequency of making careless mistakes, (e.g., “I make careless errors when completing task”), which is in line with difficulties in detecting the need for self-control (i.e., you make careless mistakes because you do not detect the discrepancy between goal and outcome.). The shifting subscale measures problems in switching from one task to another and deficits in problem-solving flexibility (e.g., “I have trouble changing from one activity or task to another”), which would could be in line with problems in adjusting behavior when it is not in line with goals (e.g., “not shifting back to the main task following mistakes). The items on the inhibition subscale (e.g., “I have trouble sitting still”) have some parallels to persistence, because persistence requires inhibiting the impulse to pursue other goals or give up pursuit of the current goal. Prior research shows that scores on the BRIEF are lower for individuals who have self-control issues (e.g., children with attention deficit/hyperactivity disorder; Yers et al., 2009) and are related to outcomes indicative of lower abilities in self-control (e.g., academic performance; Rabin et al., 2011), which have also been related to psychophysiological and behavioral measurements of self-control.

One limitation of these scales is that they assess perceived self-control rather than actual self-control. That is, people may report that they are high (or low) in self-control, based on highly biased evidence from their lives (e.g., cognitive distortions), when in fact they are not. This is one interpretation of the small-to-nil correlations between self-report and behavioral measures of self-control (e.g., Cyders & Coskunpinar, 2011; Toplak, West, & Stanovish, 2013). Another interpretation is that measures like the BRIEF index problems in self-control as they manifest in everyday life (e.g., academic procrastination; Rabin et al., 2011), whereas the special conditions that are set up for psychophysiological and behavioral tasks in the laboratory may capture different abilities in self-control that may or may not overlap with everyday ability. With either interpretation, it is useful to triangulate self-report measures with psychophysiological and behavioral indices for more well-rounded measurements of self-control ability. Finding similar results across different modalities (e.g., self-report and behavior) provides stronger evidence that the result may be due to a core aspect of self-control (i.e., the shared variance) than results that only exist for one modality (e.g. self-report).

In terms of psychophysiology, the most well-known index of the monitoring aspect of self-control is the error-related negativity (ERN; Gehring et al., 1993). The ERN, an event-related potential that is a negative deflection maximal at midline sites, peaks between 50 and 200 milliseconds (ms) following an error of commission. The ERN is proposed to be a neural signal that detects the discrepancy between the actual and correct response, with larger (i.e., more negative) ERNs being related to increased detection of an error (Botvinick et al., 2001; Yeung, Botvinick, & Cohen, 2004). Thus, a larger (more negative) ERN is an index of increased monitoring ability and is related to self-control outcomes (e.g., academic performance; Hirsh & Inzlicht, 2010; substance use relapse; Marhe, van de Wetering, & Franken, 2013). Research has found a high test-retest reliability for the ERN, suggesting that it is a stable, trait-like measure (Myer, Bress, & Proudfit, 2014; Weinberg & Hajcak, 2011). In terms of ERN relationships with self-report measures of monitoring, only one prior study examined this and found no significant correlation between ERN and task monitoring on the BRIEF (Chang, Davies, & Gavin, 2009); however, this study had a small sample to detect the small correlations that might be expected.

An ERP component related to the ERN is the feedback related negativity (FRN). The FRN is a peak that is more negative in response to feedback than an error was made (e.g., loss) compared to positive feedback (e.g., wins). The FRN seems to reflect reactivity to reward versus punishment. Increased FRN has been related to self-report measures of reward sensitivity (Bres & Hajcak, 2013) and reduced FRN has been found in depression, which can be characterized by an insensitivity to reward (Kujawa, Proudfit, & Klein, 2014). The theoretical link between ERN and FRN comes from probabilistic learning tasks (Holroyd, Yeung, Coles, & Cohen, 2005), which show that the FRN is elicited while the participants are learning the response mappings (i.e., the brain response is to the feedback), but once the participants learn which responses are correct and incorrect, the ERN is elicited (i.e., the brain response is to the button press prior to the feedback). Thus, both the FRN and ERN are indexes of error detection but they are occur at different stages in the learning process. To my knowledge, no study has examined whether FRN is correlated to self-reported problems in task monitoring.

In terms of measures of adjustment relevant to error monitoring, behavioral measures are most used in the literature (Robinson et al., 2010). Behavioral adjustment has been operationalized as the tendency for individuals to slow down on the trial following an error of commission on cognitive tasks (Rabbit, 1966; Robinson, 2007). This post-error slowing (PES) is thought to reflect an increase in response caution (Botvinick et al., 2001; Dutilh et al., 2012). Thus, following an error, adjusting one's responding speed prevents a subsequent error. Individual differences in the tendency to slow down following an error have been related to academic performance (Hirsh & Inzlicht, 2010) and emotion regulation (Robinson, 2007). No prior study has reported the correlation between PES and problems in shifting on the BRIEF.

The last aspect of self-control, persistence, has been measured by a variety of behavioral tasks, some of which require participants to tolerate either physical or emotional distress (for a review see Leyro et al., 2010). One commonly used task that captures the ability to persist during psychological distress is the mirror-tracing task, which requires participants to persist at a difficult and frustrating task for as long as they can (i.e., tracing objects as if looking in a mirror). Previous research has shown that compared to healthy controls, individuals with substance use disorders have poorer performance on this task (McHugh & Otto, 2012; Quinn, Brandon, & Copeland, 1996). Additionally, poorer performance on this task is related to relapse among smokers and treatment drop-out among substance users (Brown et al., 2002; Daughters et al., 2005). Another measure of persistence, specific to persistence in the face of physical discomfort, involves measuring participant's ability to hold their breath. Similar to the mirror-tracing paradigm, shorter breath holding times are related to relapse, particularly among smokers (Brown et al., 2009; Hajek et al., 1987). No prior studies have examined the correlation between these measures and the inhibition subscale of the BRIEF.

Previous research has found group differences on the three aspects of self-control when comparing individuals with and without a substance use disorder. For example, compared to controls, individuals with cocaine dependence (Franken et al., 2007; Sokhadze et al., 2008), nicotine dependence. (Luijten et al., 2011), marijuana dependence (Forman et al., 2004), and opiate dependence (Hester et al., 2013) have smaller ERNs, indicating reduced monitoring of the need for self-control (for null results see Franken, van Strien, & Kuijpers, 2010). Similar results exist for adjustment, specifically PES (Hester et al., 2013; Lawrence et al., 2009; Luijten et al., 2011), and persistence (Brown et al., 2002; Daughters et al., 2005; Hajek et al., 1987; McHugh & Otto, 2012).

There are three main limitations to the aforementioned research in this area. First, the cross-sectional nature of these studies does not inform us on the ability of self-control to predict future substance use, and the few longitudinal studies looking at ERN and substance use that do exist focus on relapse following treatment (e.g., Luijten, Kleinjan, & Franken, 2016; Marhe et al., 2013; Matheus-Roth, Schenk, Wiltfang, Scherbaum, & Muller, 2016), which may not generalize to use among current users who may not be interested in abstaining. Second, because this work compares users and non-users, it does not allow inferences about how self-control might be related to the maintenance of substance use, once started. Finally, few of these studies incorporate the interaction between trait self-control and state negative affect, and to my knowledge no study has looked at multimodal assessments of self-control in conjunction with state negative affect and illicit substance use in the participant's natural environment.

Current Study

The primary goal of this study was to examine whether different aspects of self-control (monitoring, adjusting, and persisting) measured using multiple instruments (self-report, psychophysiological, behavior) moderate the relation between negative affect and illicit substance use in a sample of current substance users with a history of substance use disorders. For purposes of identifying the specificity of the negative affect-substance use relationship, secondary analyses explored whether self-control moderated substance use links to *positive* affect. In order to address a number of limitations of the current literature, this study used a combination of laboratory tasks and ecological momentary assessment. In sum, the multi-method approach allowed for well-rounded measurement of self-control ability, while simultaneously reducing retrospective reporting of affect and substance use, and thus, increasing ecological validity.

The proposed study had three hypotheses. First, momentary negative affect at one time point, as assessed during with ecological momentary assessment, was expected to prospectively predict substance use at the subsequent time point, consistent with research on non-illicit substances (e.g., Armeli et al., 2007; Buckner et al., 2012). Second, because monitoring is necessary but not sufficient for self-control (e.g., Robinson et al., 2010), it was predicted that individual differences in monitoring would not moderate the relation between momentary negative affect and substance use[2]. Third, consistent with the proposed model, it was predicted that individual differences in adjustment and persistence would moderate the negative affect - substance use relation, such that at low levels of adjustment and persistence, there would be a positive relation between negative affect and substance use. This relation, however, will not be present at high levels of adjustment and persistence.

I considered the analyses in regard to positive affect exploratory for two reasons. First, although there is theory suggesting that positive affect plays a role in continued substance use (e.g., Cooper, 1994; Patrick et al., 2016), there has been limited prior research and theory to guide predictions of how self-control might moderate this relation. Second an argument could be made for two mutually exclusive moderating relations. One the one hand, the relation between positive affect and substance use may be stronger at *higher* self-control among current users because one motive of use is to enhance positive affect. On the other hand, the relation between positive affect and substance use may be stronger at *lower* self-control because one study found that people who are high in positive urgency (i.e., the tendency to be impulsive during periods of positive affect) are more likely to engage drinking behavior during periods of positive affect (Cyders et al., 2010). Given the lack of clear hypotheses, these analyses were considered exploratory.

[2] Although in null hypothesis significance testing, it is generally not advised to predict the null, in interval estimation it is possible to show that the point estimate is essentially zero and the confidence interval is so narrow around zero that the inference of no effect is warranted (e.g., Cummings, 2014)

CHAPTER 2

METHOD

Participants

Participants for this study were recruited from two sources. Sixteen participants were recruited from a pool of participants who completed a previous study in our lab (for published results, see Edwards & Verona, 2016; Mager, Bresin, & Verona, 2014; Verona, Murphy & Javdani, 2016). An additional 45 participants were recruited from advertisements in the community, including Craigslist, Reddit, and word of mouth. There were slightly different inclusion criteria used for the two sources, based on the amount of information available prior to participants coming into the lab.

Participants from the previous study were selected from a sample of 318 participants recruited from the community and substance use treatment centers. The eligibility criteria for the parent study were: substance use, aggression, and/or criminal charges related to either substance use or aggression in the last six months. In the parent study, the substance use module of the *Structured Clinical Interview for DSM-IV-TR Axis I* (SCID-I; First, Spitzer, Gibbon & Williams, 2002) was administered to obtain diagnostic and symptom information for alcohol use and substance use disorders. From this sample, those who indicated that their *most problematic drug* was something other than marijuana or alcohol and met diagnostic criteria for a substance use disorder for this most problematic drug, were contacted via email or phone and asked about recent substance use and ownership of a smart phone (*N* = 167). I was able to reach 30 of these potential participants because we no longer had working phone numbers for many of them. Those who reported no use of any substances (including alcohol or marijuana) in the last month or no access to a smartphone were not invited to participate in the current study (*N* = 10). Of those remaining, 20 agreed to participate and 16 showed up to the session.

Participants recruited anew for the study contacted the lab based on paper or electronic advertisements and were screened via email or phone for recent (i.e. last month) alcohol and substance use and ownership of a smartphone. Potential participants who reported any use of illicit substances, other than or in addition to marijuana (alcohol use was neither inclusionary or exclusionary), in the last month and who owned a smartphone were invited to participate. For these participants, the SCID module for the assessment of substance and alcohol use disorders was completed at the start of the laboratory session. Thus, unlike those recruited from the previous study, the inclusionary criteria involved only current illicit substance use, but not necessarily a substance use disorder (although the latter was assessed at the laboratory session).

In sum, a total of 61 participants (*n* = 29, 47% women) participated in the study. Table 1 shows the demographic information for the entire sample and by recruitment source. The two recruitment subsamples differed on ethnicity, education, and income, with those recruited from the previous study more likely to be older, of lower income and education levels and self-identify as Black/African American. They did not differ on gender (p = .416) or ethnicity (p =.289). Given group differences, relevant demographic variables and recruitment source were explored as covariates.

Substance use history. Even though participants were recruited for historical and recent use of illicit substances other than marijuana, 43% (*n* = 26) reported marijuana as their most problematic drug of use (exclusively those from the newly recruited subsample). Cocaine (*n* = 14, 23%) and opioids (*n* = 11, 18%) were the next most commonly reported problematic drugs. Other substances that were less common were stimulants (*n* = 2, 3%), sedatives (*n* = 1, 2%), and polysubstance use (*n* = 4, 7%). Recruitment source did not significantly differentiate those endorsing cocaine (old: 64% of cocaine users; new: 36%, *p* = .423) or opioids (old: 36%; new: 63%, *p* = .548) as the most problematic drug. The small numbers for stimulants, sedatives, and polysubstance use made it difficult to determine whether differences in these endorsements differed across recruitment source.

Based on the SCID and *DSM-IV* criteria, participants had an average of 3.27 (*SD* = 3.15) lifetime symptoms of alcohol use disorders and 5.34 (*SD* = 3.95) lifetime symptoms of substance use disorders. About 53% (*n* = 34) met lifetime criteria for an alcohol use disorder and 73% (*n* = 44) met lifetime criteria for a substance use disorder. Individuals recruited from the previous study had significantly more lifetime symptoms for both alcohol and substance use disorders (see Table 1) and were more likely to have a lifetime diagnosis of alcohol (*OR* = 8.40, 95% CI [1.70, 41.43]) or substance (*OR* = 7.75, 95% CI [.93, 64.51]) use disorder. Substance use disorder symptom counts (i.e., number of symptoms) were also explored as covariates.

Procedure

The study consisted of two aspects, a laboratory session, where individual differences in self-control were assessed, and a 14-day ecological momentary assessment protocol, where state negative affect, positive affect, and substance use were measured.

Laboratory session. After providing consent, participants who had not completed the previous study were interviewed for alcohol and substance use disorders with the substance use module of *SCID* by the author (an advanced PhD student). Additionally, all participants provided information about the number of alcohol and substance use days in last week via a timeline follow-back (TLFB) interview (Sobell & Sobell, 1992). Next, the EEG cap and electrodes were applied. During this time, participants completed demographic questionnaires.

Once the EEG cap was attached, participants completed a variant of the flanker task (Eriksen & Eriksen, 1974; Hall et al., 2007), which yielded the ERN and PES, and completed the doors task, which yielded the FRN. Following these tasks, the EEG electrodes were removed. Then, the participants completed the mirror-tracing (Strong et al., 2006) and breath-holding tasks (Zvolensky et al., 2001), which assessed the persistence-based aspects of self-control (psychological and physical persistence, respectively). Finally, participants were given instructions for the ecological momentary assessment protocol at the end of this session.

Ecological momentary assessment. The ecological momentary assessment protocol consisted of 4 ratings per day (prompts sent at 10am, 1pm, 4pm, and 7pm) for 14 days. Participants completed the assessments on their smart phone via a secure website (i.e., Qualtrics). Participants received emails with links to the surveys at the scheduled times and had until the next email to complete them (i.e., 3 hours), aside from the final prompt when participants were informed to complete surveys before they went to bed. Within the same day, prompts were completed on average 3.71 hours apart with a standard deviation of 2.88 hours. All participants started the protocol the day after their laboratory visit and continued for 14 days. Approximately 7 days after their laboratory session, participants visited the lab to get paid for their first week of the momentary assessment. This was done to increase compliance (cf., Engel et al., 2013; Smyth et al., 2007). During this visit, participants also completed a TLFB interview to assess alcohol and substance use days in the last week. Similar procedures were completed at the end of the second week.

Across the 14 days of the ecological momentary assessment, participants completed an average of 38 (*median* = 40, *mode* =35, *min* = 3, *max* =56) out of 56 possible surveys (two participants completed no surveys), leading to 67% compliance (*median* = 72, *mode* =63, *min* =

5, *max* =100), which is in line with previous studies with other substance using samples (Buckner, Crosby, Wonderlich, & Schmidt, 2012; Serre et al., 2012). Participants completed slightly fewer surveys during the second week (M = 19.23, SD = 7.12) compared to the first week (M = 20.53, SD = 5.57), but this difference was not significant, $t(111) = 1.08$, $p = .282$, d = -.29. Within a day, when participants responded to one prompt, they responded to the next prompt 93% of the time. This suggests that when participants missed prompts, they tended to miss entire days, not certain prompts within days. Participants were marginally more likely to miss the next prompt when they reported substance use at the current prompt, $t(1753)=1.85$, p = .064; however, the difference was small (94% versus 92%, OR = 1.39, 95% CI [.98, 1.97]). This suggests that substance use at one time point had minimal effects on compliance at the next prompt.

Given that there are no agreed upon guidelines for how much compliance is enough and the researcher degrees of freedom involved in defining a compliance rate to be included in the study (e.g., Simmons, Nelson, & Simonsohn, 2011; Wicherts et al., 2016), I included all participants and then conducted a follow up analysis that included compliance as a covariate.

Laboratory Measures and Tasks

Timeline follow-back. The timeline follow-back (TLFB) interview uses memory cues (e.g., birthdays) to help reduce recall bias when reporting recent substance use (Sobell & Sobell, 1992). Participants are first asked to report any major events that happened to them in the last week. Then participants report drug and alcohol use day by day. A large body of research shows that the TLFB interview is reliable and has good validity for alcohol and illicit substance use (Hjorthøj, Hjorthøj, & Nordentoft, 2012; Hoeppner, South, Jackson, & Barnett, 2010; Sobell & Sobell, 1992). Studies that have compared the TLFB to ecological momentary assessment reports of substance use show that ecological momentary assessment data tends to be more accurate (i.e., less rounding errors; Shiffman, 2009). We had TLFB for three time points: the week before the ecological momentary assessment protocol (TLFB-Pre), the first week of the protocol (TLFB Week 1) and the second week of the protocol (TLFB Week 2). In this study, the TLFB method was used to assess whether participating in the ecological momentary assessment daily would affect substance use. We compared the number of alcohol and substance use days reported on the TLFB from the week before the ecological momentary assessment protocol to that reported during the protocol. These data were also used to provide convergent validity for the ecological momentary assessment data by showing similar estimates for the number of alcohol and substance use days during the protocol period.

Behavior Rating Inventory of Executive Function (BRIEF). To measure self-reported aspects of self-control, the BRIEF (Roth et al., 2005) was administered. It is a 75 item self-report measure of executive function. The items load on to nine different subscales. I focused on three (task monitoring, shifting, and inhibition), based on their conceptual overlap with monitoring, adjusting, and persistence. Participants rated items on a three-point scale (0 = *never a problem*, 1 = *sometimes a problem,* 3 = *often a problem*) as to the amount of difficulties in functioning they experienced in each of these domains in the last 6 months. The task monitoring subscale contained 6 items (sample item: "I make careless errors when completing task."; $\alpha = .82$) and indicated the extent to which the individual had problems with mistakes in their work. The shifting subscale contained 6 items (sample item: "I have trouble changing from one activity or task to another."; $\alpha = .81$) and indexed problems in adjusting from one task to another. The inhibit subscale contained 8 items (sample item: "I have trouble sitting still."; $\alpha = .79$) and indexed problems with patience and waiting for one's turn.

Flanker task. The flanker task requires participants to respond with a button press to a central stimulus (H or S) flanked by two letters on each side, which can be congruent (e.g., SSSSS) or incongruent (HHSHH; Eriksen & Eriksen, 1974). To increase task complexity (and thus the number of errors), a non-target (X) was displayed (with congruent or incongruent flankers) on 16% of trials, and participants were instructed to withhold responses to these non-targets (Hall et al., 2007). For each trial, the stimulus array was displayed for 150 ms and participants had up to 1400 ms to respond. The inter-trial interval varied among 1500, 2000, and 2500 ms. After a practice block, participants completed six blocks of 100 trials each. To further increase task complexity, response mappings (left hand for one target letter, right hand for the other target letter) changed between blocks.

Response time and accuracy of responding were recorded along with EEG. EEG was recorded with a 32 channel stretch lycra electrode cap (Electrocap, Eaton, OH) using the 10–20 international system. Analog signals were digitized at 2,000 Hz with a .15–200 HZ bandpass filter using Neuroscan2 amplifiers (Compumedics, Charlotte, NC). This task was used to measure one aspect of monitoring (ERN) and adjusting (PES).

Doors task. The doors task requires participants to choose between two doors presented on a screen as to which they think has a prize behind it (Kujawa et al., 2014). On each trial, participants are shown the two images of doors on the right and left hand sides of the screen. After participants choose one door by pressing a button on the keyboard, they are shown a fixation for 1,000 ms and then feedback for 2,000 ms. Participants are told that if they see a green arrow pointing up, they have won $0.50 on that trial, whereas if they see a red arrow pointing down, they have lost $0.25 on that trial. The different values for wins and losses are based on prior research showing that losses loom larger then rewards; thus even though they are different numerical values, they are roughly equivalent in subjective win/loss value (Hajcak, Moser, Holroyd, & Simons, 2006). There was a total of 60 (30 wins and 30 losses) trials displayed in 3 blocks of 20. After the task, participants were correctly told that they had earned an additional $5.00 of payment. EEG was recorded during this task and it was used to calculate another ERP measure of monitoring, the FRN.

Mirror tracing. Persistence in the face of emotional distress was measured with the mirror-tracing task, which requires participants to use the computer mouse to trace objects on the computer screen (Strong et al., 2006). However, the mouse and cursor movements are opposite (e.g., moving the mouse down leads the cursor to go up). Moreover, when participants made a mistake, a loud buzz sound was played and participants were brought back to the beginning of the object. There were three different shapes to trace. The first two are relatively easy (e.g., a straight line) and have time limits. The third shape, on which participants have unlimited time, is a star, which is difficult to trace. For this shape, participants are told to press any button when they wish to terminate the task. No reward was provided for continuing longer on the task. The time spent working on the difficult star shape was recorded as an index of persistence.

Breath holding. Persistence in the face of physical distress was measured by a breath holding task. As in previous research (Zvolensky et al., 2001), participants were asked to breathe normally for 30 seconds, and then completely exhale and hold their breath for as long as they could. A timer was started once participants completed their exhale and stopped when they took a breath in. This process was repeated for a total of three trials, which were averaged as a measure of persistence.

Multimethod Self-control Measures

Monitoring. Monitoring was operationalized in three ways: self-reported problems in task monitoring on the BRIEF, ERN from the flanker task, and FRN from the doors task. The ERN was calculated using the physbox add on the EEGlab toolbox in Matlab (Curtin, 2011; Delorme & Makeig, 2004) from the flanker task. First, the EEG data were re-referenced to the average of the two mastoids. Then a .1-30 Hz butterworth filter was applied. Blink artifacts were removed using a regression procedure proposed by Semlitsch et al., (1986). Next, the trials were epoched, with from 500 ms before the response until 1000 after the response and then averaged for correct and incorrect trials within-participant. Consistent with other research (e.g., Meyer, Hajcak, Tropey-Newman, Kujawa, & Klein, 2015; Weinberg, Klein, Hajcak, 2012), we subtracted the average activity from -500 to -300 ms from each data point to adjust the baseline. The ERN and correct-related negativity were defined as the average activity from 90 to 190 ms post response (cf. Weinberg et al 2012). Participants made an average of 54.46 errors on the task (*min* =2, *max* = 386), which is well above the recommended number of error trials to calculate the ERN (i.e., 6; Weinberg & Hajcak, 2011). Although one participant was below the recommended number of trials for a reliable average ERN, the statistical significance of the results did not change whether they were included or not; therefore, I included them in the ERN analyses because even with their limited data, they should help improve the precision of the estimates (Cumming, 2014). A difference score was created by subtracting the correct-related negativity from the ERN, which means that negative values indicate *more* monitoring.

The initial steps for the FRN were similar to ERN (e.g., re-reference to the average mastoid). For FRN, the epochs were 500 ms before the onset of feedback to 600 ms post feedback on the doors task. These epochs were then averaged within-participant for wins and loss feedback separately. In line with other research with the doors task (e.g., Kujawa et al., 2014), the FRN was defined as the average amplitude from 275 to 375 ms following the onset of the feedback. A difference score was created by subtracting the win feedback trials from the loss feedback trials. As with the ERN, negative values indicate *more* monitoring.

Adjusting. Adjusting was operationalized as self-reported shifting problems on the BRIEF and with our behavioral index of PES. PES, or slowing of reaction time following error trials, was extracted from the flanker task used to extract ERN. First, trials that were excessively fast (<150 ms) or slow (> 1,000) were dropped (5% of trials). Then, two averages were calculated for each participant, one for the reaction time on correct trials following an error and the other for reaction time on correct trials following a correct trial. A difference score was calculated by subtracting reaction time for trials following correct trials from reaction time following incorrect trials (e.g., Robinson, 2007; Wilkowski & Robinson, 2008); thus, positive values indicate more adjusting.

Persistence. Persistence was operationalized in three ways, self-report inhibition problems on the BRIEF, time until “quitting” on the mirror-tracing task, and the average of the three breath-holding times.

Ecological Momentary Assessment Measures

Momentary negative affect. Each momentary assessment began with participants completing the 20-item Positive and Negative Affective Schedule (PANAS; Watson, Clark, & Tellegen, 1988). Participants indicated how they felt “right now in the current moment” on a 5 point Likert-type scale (1 = *not at all/slightly*, 5 = *extremely*). The PANAS has two subscales, positive affect (e.g., “excited”; $\alpha = .92$) and negative affect (e.g., “distressed”; $\alpha = .88$), each indexed by 10 items. The PANAS has been used in several ecological momentary assessment studies (Engel et al., 2014; Trull et al., 2008) and has adequate psychometric properties (Burg et al., 2013; Watson & Clark, 1995; Watson et al., 1988).

Substance use. At each assessment, participants reported whether there had been any use of alcohol and/or illicit drugs (marijuana, cocaine, amphetamines, opioids, or other) since the last assessment. Participants were instructed to report any substance use that occurred after the last survey of the day (~ 7 pm) at the next morning's assessment. Each survey was time stamped, so that day of the week and time of day could be used as covariates if necessary.

Data Analytic Plan

Because of the nested nature of the data (i.e., moments nested within-participants), multi-level modeling was used to test the hypotheses unless otherwise noted. Multi-level modeling parses variance into multiple components (i.e., for each level) and allows the researcher to fit a model to explain variance within each level (Singer & Willett, 2003). Multi-level modeling is also advantageous for ecological momentary assessment data because it is robust to missing data at lower levels (e.g., missing assessments within a day; Judd, Westfall, & Kenny, 2012). Given that the primary outcome is a binary variable (0 = no substance use, 1 = substance use), I used a generalization of multi-level modeling for non-linear models (Little, Milliken, Stroup, & Wolfinger, 2006). I report *p*-values along with confidence intervals, consistent with current recommendations in the literature (e.g., Cumming, 2014).

Preliminary Analyses

Prior to the main analyses, I conducted several sets of analyses to better understand these data. First, I ran site (Fz, Cz, CPz, Pz) by accuracy (error/loss, correct/win) repeated-measures ANOVAs on the ERN and FRN data to ensure that the expected effects were present in these data. Second, I looked at correlations among indices of self-control. This was done by looking at between-subject Pearson's correlations. Based on prior research (Cyders & Coskunpinar, 2011; McHugh & Otto, 2012), it was expected that the correlations would be small-to-nil. This was however, deemed informative because no study to my knowledge has included this combination of self-control indices.

Next, I ran a series of analyses to identify covariates that would be useful for the main analysis. Given that participants from the two recruitment sources differed on age, race, education, income, and lifetime alcohol and substance use disorder symptoms, I examined whether these between-subject factors were related to reported substance use in the ecological assessment portion of the study (the main dependent variable), as well as whether reported substance use varied as a function of recruitment source. In these models, the log odds of substance use at the current time point in ecological portion of the study served as the dependent variable and the potential covariate as the Level 2 predictor variable. A second set of analyses looked at whether the within-subject factors of time of day (i.e., survey 1-4) and day of the week (i.e., weekend versus weekday) had a relation with substance use. This was based on previous studies that have found that substance use is more likely to occur in the evening and on weekends (e.g., Buckner et al. 2012; Hopper et al., 2006). In these analyses, time (mean-centered) and weekend (effect coded) and their interaction served as Level 1 predictors of substance use.

Finally, I examined patterns of substance use during the ecological assessment part of the study to better characterize the dependent measure. Thus, I calculated the percentage of prompts where substance use occurred, the number of substance use days, and number of different substances used. To help establish that participating in the ecological momentary assessment did not change the participants' use or reporting of substance use, I compared the number of alcohol and substance use days from the week before the study, as assessed via TLFB (TLFB-Pre) to the estimates from the ecological portion of the study. For convergent validity, I also compared the number of alcohol and substance use days as assessed from the ecological portion of the study to the TLFB interviews conducted following week 1 and 2 (TLFB Week 1 and Week 2).

Primary Analyses

To test the first hypothesis that state negative affect would prospectively predict substance use, the Level 1 (within-subject) model contained negative affect at the preceding assessment (i.e.., $time_{t-1}$) to predict substance use at the current assessment (i.e., $time_t$). Negative affect was centered within-subjects, which unconfounds between-subject and within-subject variation (Curran & Bauer, 2011; Enders & Tofighi, 2008) and allows for the slope to be interpreted as a purely within-subject effect (i.e., change from that person's average). It was predicted that the relation between $time_{t-1}$ negative affect and $time_t$ substance use would be positive and confidence interval will not contain zero.

To test hypotheses 2-3 (the interactions between trait self-control and state negative affect), a series of models were fit. In each model, one individual difference measure of self-control (e.g., task monitoring on the BRIEF) was added as a Level 2 predictor. Additionally, significant covariates (i.e., age; time, day of week) were included. Of more importance was the cross-level interaction between self-control and negative affect at $time_{t-1}$. It was predicted that this interaction would be significant for adjustment (shifting on the BRIEF and PES) and persistence (inhibition on the BRIEF, mirror-tracing time, breath holding time) but would not be significant and have a tight confidence interval around zero for monitoring (task monitoring on the BRIEF, ERN, FRN). Significant interactions were followed up with generalizations of Aiken & West's (1991) methods for probing interactions between continuous variables (Preacher, Curran, & Bauer, 2006). Specifically, the relation between negative affect and substance use was examined at high (+1 *SD*) and low (-1 *SD*) levels of self-control. It was predicted that the slope would be significant and positive at low levels of adjustment and persistence. Secondary analyses were conducted with positive affect in place of negative affect, to determine specificity of effects.

Finally, I conducted some robustness analyses to see whether effects were still significant when adjusting for positive affect, recruitment source, and compliance with the ecological momentary assessment procedure.

CHAPTER 3

RESULTS

Missing data

Due to a variety of reasons, some participants were missing data on tasks or assessments. One participant used the wrong keys on the flanker task, and did not have usable data for ERN and PES. There were EEG recording errors for two participants on the flanker task, leaving a total of 58 participants with ERN data. One person was missing mirror-tracing data, and one person was missing the BRIEF, both due to experimenter error. In addition, two participants did not complete any surveys during the ecological momentary assessment portion of the study. Thus, there were slightly different *N*'s for each analysis ranging from 57 to 61. I used all available data in each analysis to avoid post hoc justifications for excluding participants (e.g. Simons et al., 2011)

Event-related Potentials

For ERN, there was not a significant main effect of accuracy, $F(1, 56) = 1.68$, $p = .200$, but there was a main effect of site, $F(5, 280) = 5.31$, $p < .001$, and an accuracy x site interaction, $F(5, 280) = 4.01$, $p = .001$. Follow-up paired-sample *t*-tests showed that there was a significant effect of accuracy at CPz, Cz, and FCz (*p*'s < .025, *d*'s < -.30), a marginal effect at Fz ($p = .086$, $d = -.23$), and no significant effect at Pz ($p = .854$, $d = .02$). In order to maximize the reliability of the ERN as an individual difference measure, I used the average across FCZ, CZ, and CPZ sites.

For FRN, there were significant main effects of feedback, $F(1, 59) = 11.10$, $p = .002$, site, $F(5, 295) = 3.93$, $p = .002$, but not a significant feedback x site interaction $F(5, 295) = 1.13$, $p = .345$. The follow-up tests showed that the effect of feedback was significant for each site (*d*'s < -

.34), but was numerically largest at Cz. Similar to ERN and other research (Kujawa et al., 2014), I used the average across FCZ, CZ, and CPZ to calculate the FRN. The appendix on page 78 has figures that display waveforms for a subset of electrode sites and average waveforms.

Correlations Among Self-control Indices

The correlations among the different measures of self-control are displayed in Table 3. Consistent with other research (e.g., Letkiewicz et al., 2014), all subscales of the BRIEF were positively and significantly correlated with each other at moderate-to-large effect sizes. There was some evidence of correlations among different measures of the same aspects of self-control. For example, there were small, but not significant, positive correlations between self-reported problems in task monitoring and FRN (more problems monitoring, less differentiation between wins and losses) and ERN. There was statistically significant correlation was between PES on the flanker task and the shifting subscale of the BRIEF. The correlation was moderate in size and indicated that fewer problems with shifting in everyday life were related to greater PES. The correlations among the persistence measures were small and close to zero. There was also some evidence of overlap across different aspects of self-control. For example, problems inhibiting were significantly correlated with both ERN and PES both with small effect sizes.[3] The limited significant correlations across the measures is not uncommon in the literature (Cyders & Coskunpinar, 2011; McHugh & Otto, 2012), but also may be influenced by limited statistical power for small to medium correlations (i.e., power for r = .3 was .66; power to for r = .25 was .50).

[3] Breath holding was the only self-control measure with a significant difference between recruitment sources on self-control (d = .66), with participants from the prior study having lower values.

Identifying Covariates

To determine between-subject covariates, I ran 8 separate models where I considered one potential between-person covariate at a time (i.e., age, race [White, Black, and other effect coding], income[4], education, symptom counts of substance use disorder, symptom counts of alcohol use disorder, and sample recruitment source) to predict reports of substance use since the last period of ecological momentary assessment. Then, I ran one additional model with all potential covariates entered simultaneously to predict reports of substance use. In separate models, none of the potential covariates was significantly related to reports of substance use. When entered simultaneously, age was significantly negatively related, b = -.07, 95% CI [-.12, -.02] t(41.73) = -2.84, p = .007, and thus was retained a covariate throughout the analyses.

To look at whether time of day or day of the week were related to reports of substance use, I ran a model with time of day (mean-centered) and day of the week (effect coded as to Friday and Saturday versus other days of the week), and their interaction, predicting substance use at the current assessment. Time was not related to substance use, b = .001, 95% CI [-.09, .10], t(2244) = 0.00, p = .994, but day of the week b = -.11, 95% CI [-.22, -.01], t(2244) = -2.11, p = .035, and their interaction, b = -.12, 95% CI [-.32, -.02] t(2244) = -2.46, p = .014, were related to reports of substance use. The nature of this interaction was that time of day was negatively related to the probability of substance use on weekdays, b = -.12, 95% CI [-.22, -.02], t(1624) = -2.46, p = .014, with the likelihood of substance use decreasing throughout the day on weekdays, whereas the effect was non-significantly in the opposite direction during the weekends, b = .12, 95% CI [-.03, .28] t(619) = 1.49, p = .136. This finding likely reflects the fact that on weekdays, participants were most likely to use substances in the evening, but not

[4] Following the suggestion of one of my committee members, I explored whether the relation between negative affect and substance use varied as a function of income. The interaction was not significant (b = -.01, 95% CI [-.12, .10]), nor was the main effect of income on substance use days (b = -.09, 95% CI [-.25, .06]).

report them until the next morning, whereas on weekends, participants were equally likely to use substances throughout the day with a trend toward using later in the day. Based on these results, time of day, day of the week and their interaction were included in all subsequent models.

Descriptive Analyses and Frequency of Substance Use

During the ecological momentary assessment, participants used any substance an average of 9.50 (*SD* = 4.17, *median* = 11, *mode* = 14, *min* = 0, *max* = 14) days out of the 14. Eighty-two percent of participants (*N* = 49) reported substance use on 6 or more days of the 14-day study period. However, recruitment source differences were observed for number of substance use days. Participants recruited anew reported more overall substance use days (*d* =1.11), marijuana use days (*d* = .97), and alcohol use days (*d* = .60). The two sources did not significantly differ for other substance use days (*d*'s ranged from -.25 for cocaine to .53 for opioids). These results suggest that, although the participants from the previous study had more lifetime symptoms of substance use disorder, the newly recruited participants were currently using substances more frequently.

On substance use days, the majority of participants reported using 1 (28% of use days), 2 (26%), or 3 (20%) times per day. On average, participants reported using substances 25.83 times during the study period (*SD* = 17.63, *median* = 24, *mode* = 7, *min* = 0, *max* = 86), with 70% of the sample using 10 or more times during the study period. Only one participant reported no substance use during the ecological momentary assessment period. The results did not change whether or not this participant was included in the analyses, so the participant was included. Participants on average reported using 2.58 (*min* = 0, *max* = 5) different types of substances during the study period. Overall, these results suggest that there was substantial substance use by the majority of participants during the study period.

To establish validity for the self-reports of substance use during the ecological momentary assessment, the data from the weekly TLFB reports of number of alcohol and substance use days were compared to the number of alcohol and substance use days calculated from the ecological momentary assessment data. Table 2 displays the means, confidence intervals, and correlations among the measures. In the week before the study (i.e., TLFB-Pre), participants reported using alcohol approximately two days per week. This is in line with the number of alcohol use days per week reported on the TLFB Week 1 and TLFB Week 2 and the reports during the ecological momentary assessment. Similar results were found for substance use days. Participants reported approximately 4 substance use days in the week prior to the study (TLFB-Pre) and during the study period (ecological assessment). These suggest little-to-no change in alcohol and substance use during the study period. Additional validity support was found in the large correlations between the TLFB and ecological assessment methods (r's > .60). These analyses help establish the validity of substance use as reported during the ecological momentary assessment period. Moreover, these analyses are evidence that participants were not affected in their reports by the act of recording substance use regularly as part of the ecological momentary assessment protocol.

Main Analyses

Contrary to my first hypothesis, negative affect at the previous time point was not related to reports of substance use at the current time point, b = -.14, 95% CI [-.38, .08], $t(2184) = -1.25$, $p = .211$. Although not significant, negative affect was instead related to a lower probability of substance use.

The second hypothesis involved the moderating role of self-control. The main effects of self-report task monitoring ($p = .940$), ERN ($p = .481$), and FRN ($p = .682$) were not significantly related to reports of substance use. Consistent with my prediction, monitoring (self-reported task monitoring or ERN) did not significantly interact with negative affect at the previous time point to predict substance use (task monitoring: b = .24, 95% CI [-.36, .85], $t(2134)$ = .76, p = .434; ERN: b = .02, 95% CI [-.02, .06], $t(2104)$ = .89, p = .373). Counter to my prediction, there was a significant interaction with FRN, b = -.04, 95% CI [-.08, -.01], $t(2132)$ = -2.42, p = .015. The nature of the interaction was that for participants with less differentiation between wins and losses (i.e., +1 *SD*), meaning less monitoring, negative affect was significantly negatively related to substance use, b = -.64, 95% CI [-1.11, -.18], $t(2132)$ = -2.73, p = .006. For participants who had a large differentiation between wins and losses (-1 *SD*; i.e., more monitoring), however, negative affect was not significantly related to substance use, b = .16, 95% CI [-.18, .50], $t(2132)$ = .92, p = .355. Follow-up analyses showed that the interaction was only significant for FRN at site CPz and did not even approach significance at the other sites. Given that this interaction was not predicted, had a counter intuitive pattern and was only significant for one site, it was not interpreted further.

For adjusting measures, self-reported shifting problems on the BRIEF did not have a significant effect on substance use (p = .912), but there was a significant interaction between negative affect and self-reported shifting problems, b = .54, 95% CI [.03, 1.04], $t(2134)$ = 2.07, p = .038. The nature of the interaction (shown in the top panel of Figure 1) was that, at low problems with shifting (-1 *SD*), there was a significant negative relation between negative affect and substance use, b = -.45, 95% CI [-.81, -.08], $t(2134)$ = -2.41, p = .014 whereas at high problems with shifting (+1 *SD*), there was a positive, although not significant, relation between negative affect and substance use, b = .07, 95% CI [-.24, .37], $t(2149)$ = .42, p = .671. The interaction of negative affect and PES was not significant, b = -.004, 95% CI [-.01, .01], $t(2140)$

= -1.34, *p* = .181, but in the same conceptual direction as for self-reported shifting (see bottom panel of Figure 1). Indeed, the simple slope of negative affect at high PES (analogous to low problems in shifting) was marginally significant and negative, *b* = -.36, 95% CI [-.75, .006], *t*(2140) = -1.93, *p* = .054, whereas it was not significant at low PES, *b* = -.01, 95% CI [-.31, .34], *t*(2140) = -.06, *p* = .953. Thus, consistent with my prediction, operationalizations of the adjusting aspects of self-control interacted with state negative affect to predict substance use; however, the nature of the interaction was more nuanced than expected. That is, people who are better able to adjust their behavior in order to achieve their goals are less likely to use substances during negative affect states, whereas negative affect plays a much smaller role among people who are less able to adjust.

For persistence, there were no significant main effects of self-reported inhibition (*p* = .249), mirror tracing time (*p* = .539), or breath holding (*p* = .701), nor did any of them interact with negative affect (inhibition: *b* = .29, 95% CI [-.30, .86], *t*(2134) = .97, *p* = .334; mirror tracing: *b* = -.00001, 95% CI [-.001, .001], *t*(2140) = -.02, *p* = .985[5]; breath holding: *b* = .006, 95% CI [-.009, .02], *t*(2141) = .77, *p* = .441), which was inconsistent with predictions.

Exploratory Analyses

Unlike negative affect, positive affect at the past time point had a significant positive relation with substance use at the next time point, *b* = .46, 95% CI [.30, .61], *t*(2184) = 5.61, *p* < .001, indicating that positive affect, not negative affect, preceded substance use. Similar to negative affect, none of the operationalizations of monitoring significantly moderated the relationship between positive affect and substance use (all *p*'s > .248), nor did either aspect of adjusting (all *p*'s > .258). Although, none of the operationalizations of persisting significantly

[5] The results regarding the mirror tracing time were the same when only including participants who reported an increase in distress from before to after the task (*N* = 56, *b* = -.0001, 95% CI [-.001, .001]) and when adjusting for the number of errors made (*b* - .0001 95% CI [-.001, .001]).

moderated the link between positive affect and substance use, analyses involving the time to quit index of the mirror tracing task revealed a possible interaction between positive affect and persistence that approached significance, $b = .0008$, 95% CI [-.0003, .002], $t(2140) = 1.38$, $p = .169$ (inhibit $p = .712$; breath holding $p = .206$). The nature of this nonsignificant interaction was that the link between positive affect and substance use was stronger for people who persisted longer during the mirror tracing task (+1 *SD*), $b = .60$, 95% CI [.34, .86], $t(2140) = 4.49$, $p < .001$, compared to those who quit earlier (-1 *SD*), $b = .32$, 95% CI [.07, .57], $t(2140) = 2.53$, $p < .015$ (see Figure 2). I cautiously interpret this to indicate that people who are good at persisting in the face of emotional distress (versus those who are not) may be somewhat more likely to engage in substance use when they are in a positive mood.

Given that negative affect and positive affect often have a small to moderate negative correlation (e.g. Watson, 2000; in this sample: $r = -.07$, $p = .555$ for between-subject; $r = -.16$, $p < .001$ for within-subjects), I re-ran all the analyses with both affect types and their interactions with self-control to predict substance use at the next prompt of the ecological momentary assessment. Results were the same as those reported above. The only change worth noting was that the p-value for the interaction between positive affect and mirror tracing time was closer to significance, $p = .087$. I also re-ran analyses of all the significant and near significant results including recruitment source and its interaction with all factors in the model. Recruitment source did not further moderate any of the results, suggesting a similar pattern for both recruitment sources.[6] I also re-ran significant analyses with compliance, as indicated by number of prompts

[6] I also ran the significant analyses separately for each recruitment source. The slopes for the shifting by negative affect interaction were in the same direction and similar in size for both sources (prior study: $b = .38$ 95% CI [-.79, 1.55}; new participants: $b = .63$ 95% CI [.08, 1.19]), although it was only statistically significant for the newly recruited participants. The follow up simple slopes tests were similar (i.e., same direction, similar size [-.29, -.51]), as were the results for PES. Differences in significance are likely due to limited statistical power for the participants from the prior study given the much smaller *N*.

completed as a covariate. The interaction for shifting was still significant (*p* =.029) and the marginal interactions for PES (*p* =.163) and mirror tracing time (*p* = .089) were still above the .05 cut off. Thus, the results appeared to be robust to covariates.

One final set of exploratory analyses examined whether intensity of substance use moderated the relation between negative affect and substance use, as it was possible that negative affect may have stronger links to substance use among heavier users. This was done in two ways. First, I examined whether the count of substance use disorder symptoms reported on the SCID at baseline moderated the negative affect substance use relation. Second, I used the TLFB-Pre as a more proximal indicator of intensity of substance use. In neither case was moderation significant (symptom count: *b* = .02, 95% CI [-.05, .09], *t*(2186) = .58, *p* = .560; TLFB-Pre: *b* = .05, 95% CI [-.05, .15], *t*(2162) = .96, *p* = .334).

CHAPTER 4

DISSCUSION

The primary goal of this study was to test whether individual differences in the monitoring, adjusting, and persisting aspects of self-control moderated the relation between negative affect and illicit substance use. Of the hypotheses, the best support was for the moderating role of the adjusting aspects of self-control in the negative affect - substance use relation; however, the pattern of results for adjusting did not fit with my hypotheses. Instead of negative affect being *positively* related to substance use at low levels of adjusting, it was *negatively* related to substance use at high levels of adjusting. My other hypotheses received limited support. In particular, most monitoring aspects of self-control did not moderate the negative affect substance use relation. This finding is far from definitive because of difficulties in interpreting null results. Counter to my prediction, momentary negative affect at one time point did not predict substance use at the subsequent time point during the ecological momentary assessment data collection period, and the persisting aspects of self-control did not moderate the negative affect – substance use link. In contrast, exploratory analyses showed that momentary positive affect was related to later substance use and there was weak evidence that this relationship is moderated by some aspects of persistence. These results provide useful evidence to advance theories of affect, self-control, and substance use, which will be explored in the remainder of the discussion.

Negative and Positive Affect and Substance Use

As mentioned in the introduction, there is a large body of theory and research suggesting that negative affect plays a role in substance use (Baker et al., 2004; Conger 1956; Koob, 2009). A closer examination of this literature, however, suggests a more complicated relation.

Laboratory studies that manipulate negative affect and measure alcohol and tobacco use find significant effects, but much smaller than would be predicted by theory (e.g., *d*'s ~ .30; Bresin, Mekawi, & Verona, in prep; Heckman et al., 2015). Moreover, studies examining substance use in participants' natural environment (i.e., ecological momentary assessment studies like this one) have found limited evidence for a strong direct relation between negative affect and substance use (e.g., Buckner et al., 2012; Dvorak, Pearson, Sargent, Stevenson, & Mfon, 2016; Shiffman, et al., 2002). Our results add to this literature by suggesting that, for current illicit substance users, positive affect but not negative affect seems to precede substance use.

There are several ways to interpret the body of results in relation to negative affect. One possibility is that the relation between negative affect and substance use is more one of avoidance of affect rather than regulation of existing affect. For instance, it is possible that current substance users have learned to anticipate unpleasant states and use substances well before negative affect occurs; thus, avoiding the experience before it starts. This may suggest that negative affect has a more historical, rather than proximal relation with substance use. Given that this study was designed to assess proximal relations, it is not well designed to test predictions derived from this model (e.g., current substance users might report less negative affect than non-users because they are successful at avoiding the experience of negative affect). Other designs would be needed to accurately test this theory.

Another suggestion is that people who are regular users, as those included in this sample, use substances for a variety of reasons in a variety of situations (e.g., after waking up, socializing with friends, with certain foods) and negative affect is just one situation where substance use occurs (Shiffman, et al., 2002). Therefore, across situations in everyday life, negative affect may not have a large role in substance use compared to other situations. This interpretation fits with

Shiffman, et al. (2002) who found that, in an ecological momentary assessment study of regular tobacco smokers, situational factors (e.g., being in an environment where smoking is allowed) were much better predictors of smoking than negative affect. Similar results have been found for cocaine and heroin (Epstein et al., 2009; Epstein & Preston, 2010). This interpretation suggests that current theories, and interventions, may want to focus on the impact of situations, more so than proximal experiences of negative affect, that lead to substance use, at least among current users.

A final interpretation that brings together the negative affect and positive affect findings of the current study is based on theoretical models emphasizing the stages of addiction (e.g., Baker et al., 2004; Koob, 2009). These models suggest that in the early stages of addiction, substance use is driven by seeking positive affect associated with substance use, but as tolerance and withdrawal develop, substance use becomes driven more by efforts to avoid negative affect. As noted in the results, the newly recruited participants were mostly a group of substance users still in the earlier stages of their use, where use is driven by the positive experiences of substance use. The participants from our previous study, however, appeared to be past their stage of heaviest use, as indicated by their lower reports of substance use during the study period compared to their higher lifetime symptoms of substance use disorder and relative to the newly recruited participants. Because the larger majority of participants in the study came from the former recruitment source, the results may not have shown a pattern of using substances to avoid negative affect (and perhaps more use of substances to enhance positive affect). Not necessarily inconsistent with either interpretation, there may be key moderators that change the way that negative and positive affect are related to substance use (e.g., self-control).

Multi-modal Assessment of Self-control and Substance Use

As with negative affect, regardless of how self-control was operationalized, it failed to show significant main effects on substance use. This is particularly surprising because prior research has suggested that self-report measures of self-control may be better able to predict everyday self-control failures (Rabin et al., 2011), but not even the BRIEF subscales predicted substance use in participants' everyday environment. This may be due to the fact that among substance using participants, substance use may not be a self-control failure, or that among current users, factors other than self-control drive substance use.

Consistent with prior research (Cyders & Coskunpinar, 2011; McHugh & Otto, 2012), I generally found small correlations between the self-report assessments of self-control and the psychophysiology and behavioral assessments. Two significant correlations across modalities did emerge: behavioral PES and self-reported shifting on the BRIEF and FRN and self-reported task monitoring. Still, these correlations were modest. Perhaps more interesting was the similarity of the moderation results for PES and self-reported shifting (see below). The fact that the interaction generalized beyond one operationalization of adjusting provides stronger support that the results are due to the latent/hypothetical construct of adjusting rather than any particular operationalization. Nonetheless, the results from this study do little to clarify the existence of small correlations among different modalities of self-control or the general lack of relationships with substance use in everyday environment.

Self-control as a Moderator of the Affect-Substance Use Relation

I had two unique predictions for the moderating role of self-control. I predicted that, because monitoring is necessary but not sufficient for self-control, it would not moderate the link between negative affect and substance use. This was supported by a nonsignificant interaction across two operationalizations of monitoring (e.g., ERN and self-reported task monitoring), although an interaction was detected for FRN in only one channel with questionable interpretability. It should be noted, however, that it is difficult to interpret null results because they may reflect a false-negative or a true null-effect. In this case, the confidence intervals were fairly narrow around zero, but were wide enough to include small effect sizes, indicating that there may be meaningful effects that would be significant in larger samples. Thus, even though the results were in line with my hypothesis, they should be interpreted with caution. Taken at face value, these results suggest that one's ability to identify the need for self-control, as assessed in both self-reported and psychophysiological measures, does not play much of a role in continued substance use following negative affective experiences. These results may seem at odds with between-group studies showing that people with substance use disorders have smaller ERNs than healthy controls (Franken et al., 2007; Sokhadze et al., 2008). The current study differs from this line of research in that I was focused on how self-control might moderate the negative affect - substance use relation among current users, not whether the cognitive processes indexed by the ERN differ between people with and without a substance use disorder. Together, extant findings may indicate that monitoring difficulties, as operationalized by ERN (and perhaps other monitoring indicators) are useful in differentiating individuals with a substance use disorder, but may not be useful in predicting future substance use among current users.

My second prediction in relation to the moderating role of self-control was that both adjusting and persisting aspects would moderate the relation between negative affect and substance use. This interaction was found for the adjustment, but not the persistence, aspects of self-control. For adjustment, self-reported adjusting and, much more modestly, behavioral adjustment (PES) moderated the negative affect-substance use relationship. The exact pattern of results did not fully conform to my predictions, with negative affect playing a role for those who are good, not bad, at adjusting. That is, negative affect did not relate to substance use at low (versus high) adjusting; instead, negative affect was *negatively* related to substance use at high, but not low, adjusting. Thus, people who are good at adjusting are less likely to use substances following negative affect.

To interpret this interaction, it is useful to reconsider the definition of the adjusting aspects of self-control, which is to adjust thoughts, feelings, and behaviors to be in line with goals once a discrepancy is noticed. Assuming that people generally have the goal of reducing negative affect (e.g., Riediger et al., 2011), it is possible that individuals high in the adjusting aspects of self-control use strategies other than substance use to change their thoughts, feelings, and behaviors to decrease their experience of negative affect. Further assuming that the strategies that people high in adjusting may have access to are more effective than using substances at reducing negative affect, overtime these individuals may become less likely to use substances during periods of negative affect. For example, if someone who is high in the adjusting aspects of self-control experiences negative affect because they have bills to pay but are not currently employed, they may be more likely to fill out job applications than use substances because it is more in line with their goal of employment. This interpretation fits with the conceptual overlap between the adjustment aspects of self-control and emotion regulation (e.g., Bonanno & Burton, 2013; Gross, 1998). Further research is needed to understand whether it is access to more strategies or access to specific strategies that explain the interaction.

Unlike adjustment, none of the indices of persistence significantly moderated the link between negative affect and substance use. This pattern of results may come from the fact that this sample included current users, and persistence may play a bigger role among those trying to remain abstinent. This is because among current users, substance use may not be as directly inconsistent with their current goals[7], whereas among people trying to maintain abstinent, substance use and their current goals are in greater conflict. In the latter case, persistence is needed to pursue one goal over another. This fits with research showing that measures of persistence are related to relapse (Brown et al., 2002).

The fact that adjusting and not persisting was found to moderate the negative affect – substance use link indicates that these two aspects of self-control rely on different strategies. Adjusting relates to making changes in the face of goal discrepancy, which explicitly reflects behavioral strategies (e.g., engaging in a behavior other than substance use). Adjusting also has direct link to negative affect, because negative affect is usually a sign of goal discrepancy (e.g., Carver & Scheier, 1998), and thus the need for change in behavior. Persisting, in contrast, does not involve change and instead involves ignoring goal-inconsistent thoughts, feelings, and behaviors (e.g., Hofmann et al., 2011), which may include negative affect, but may also include competing goals (e.g., should I study or should I spend time with friends). Thus, persistence, at least construed generally, has less of a direct link with negative affect than adjusting.

Finally, there was evidence of a marginally significant interaction between task persistence, as defined by time-to-quit on the mirror tracing task, and positive affect. The nature of this interaction was that positive affect was more strongly related to substance use among people high (versus low) in persistence. These results would support the exploratory hypothesis that using substances as a response to enhancement motives is a more controlled behavior.

[7] As argued in the introduction, using substances may be part of a long causal chain that may be inconsistent with one's goals. For example, if someone wants to maintain a job and works at an establishment that has random drug tests, using substances interferes with their work goals, but not as much as using substances interferes with abstinence goals.

However, the finding resulted from exploratory analyses and was only of marginal significance. Therefore, a replication would be necessary before this result should be interpreted further.

Limitations and Strengths

There are several limitations to consider when interpreting the results of this study. First, there are concerns about participant's ability to report accurately on their affect while intoxicated. Although valid reports of affect have been shown in laboratory studies involving alcohol consumption, there is limited data to support the validity of affective ratings under the influence in the real world (see Shiffman, 2008 for a discussion of this issue). Second, some of my results might be driven by the unique characteristics of the sample. The sample was fairly heterogeneous in many ways (e.g., demographics, substance of primary use). Even though steps were taken to statistically adjust for these differences, there may be meaningful subgroups where different results may be present. Due to university restrictions on purchasing, I was limited to participants who already owned smartphones, which may have excluded certain groups of participants (e.g., those with heavier substance use). Second, there are ways that some aspects of the ecological momentary assessment protocol might have affected the results. For example, it is possible that negative affect and substance use are related in shorter timeframes (e.g. a few minutes as opposed to a few hours). Further, I only assessed for the presence of any substance use but not the amount. Some research suggests that negative affect is predictive of heavier use (e.g., White, Anderson, Ray, & Mun, 2016); therefore, it's possible that more detailed assessment of substance use might yield different results. Third, participant's varied substance use histories could have contributed to noise in the ERPs, which may have increased the possibility of type-II errors for monitoring, suggesting the null results should be interpreted with caution. Fourth, this study was focused on substance use among current users, and may not explain how self-control and affect may be involved in relapse. Finally, all of these results are correlational, and causal claims cannot be made from these data, although some of these results may be replicated in experimental studies.

There are also several strengths of this study worth noting. First, I combined laboratory assessments of self-control with ecological assessments of affect and substance use. This design capitalized on the strengths of each method and avoided important limitations, particularly in that it replaced retrospective reports of affect with momentary reports and replaced artificial administrations of substances in a laboratory with naturalistic substance use measured in participants' natural environments. This combination of methods also contains a longitudinal component in that both self-control and affect were measured prior to the substance use. Second, I used a multi-method assessment of self-control, which in cases where the results were consistent across modes (e.g., adjusting), provide stronger evidence for the role of self-control. Finally, I recruited a clinical sample that reported heavy illicit substance use of multiple substances during the study period.

This project makes several clear additions to the substance use literature that will inform future research. Most important is the finding that the adjusting aspects of self-control moderate the negative affect-substance use relation, such that negative affect is related to less substance use among current users scoring high (versus low) in the adjusting aspects of self-control. One future direction would be to use experimental methods to determine whether training in adjustment (e.g., through cognitive bias training; Grönholm-Nyman et al., 2017) would show a similar reduction in substance use during periods of negative affect. If similar results were found, this research would have clear implications for intervention development. Another future direction would be to see whether the same relationships are present in individuals trying to remain abstinent who relapse. It is possible that negative affect and the adjusting aspects of self-control may have very different relations with substance use in the context of relapse (cf., Shiffman et al., 1996). This research would also likely have implications for intervention, as preventing lapses is a key part of early recovery.

In addition to a replication of these results in another sample, future research and theory should seek to understand the psychological processes by which individual differences in adjusting moderate the relation between negative affect and substance use (e.g., specific strategies). This study established the moderating effect of adjustment, but does not explain the mechanisms. Future studies may wish to identify the strategies that individuals high in adjustment use during periods of negative affect (e.g., attentional allocation, reappraisal, etc.). In contrast, our null moderation results for monitoring and persisting may indicate that researchers should reconsider their role in the link between negative affect and substance use. Together, the results of this paper have helped to elucidate the roles that negative affect and self-control play in substance use, which should help the development of more effective treatments to reduce the burden of substance use on society.

TABLES

Table 1 Demographics for the Entire Sample and Separately by Recruitment Source.

	Full Sample (*n* = 61)	Previous Study (*n* = 16)	New Participants (*n* = 45)
Age *M* (*SD*)	29.11 (11.63)	43.31 (12.84)**	24.06 (5.37)
Gender % (*n*)			
Men	53% (32)	44% (7)	56% (25)
Women	47% (29)	56% (9)	44% (20)
Ethnicity % (*n*)			
Hispanic	5% (3)	0% (0)	7% (3)
Non-Hispanic	95% (58)	100% (16)	93% (42)
Race** % (*n*)			
Caucasian	62% (38)	44% (7)	69% (31)
African American	18% (11)	56% (9)	5% (2)
Asian American	8% (5)	0% (0)	11% (5)
Middle Eastern	2% (1)	0% (0)	2% (1)
Latinx	2% (1)	0% (0)	2% (1)
Other	8% (5)	0% (0)	11% (5)
Education* % (*n*)			
< = High School Diploma	16% (10)	31 % (5)	11% (5)
Some College	75% (46)	69% (11)	78% (35)
> = Bachelor's Degree	9% (5)	0% (0)	11 (5)
Income* % (*n*)			

Table 1 Cont.

< 30,000	52% (31)	81% (13)	40% (18)
$30,001 - 45,000	8% (5)	19% (3)	5% (2)
$45,001 - $60,000	5% (3)	0% (0)	7% (3)
$60,001 - $75,000	8% (5)	0% (0)	11% (5)
>$75,000	27% (16)	0% (0)	36% (16)
AUD Symptoms *M* (*SD*)	3.27 (3.15)	5.91 (3.18)**	2.37 (2.63)
SUD Symptoms *M* (*SD*)	5.34 (3.59)	8.31 (2.41)**	4.28 (3.36)

Note. ** $p < .001$, * $p < .05$. For continuous variables (age, AUD symptoms and SUD symptoms), the analyses were independent samples *t*-tests. For categorical variables (ethnicity, race, education, and income), the analyses were chi-square tests for independence. < = less than or equal to; > = greater than or equal to; AUD = Alcohol Use Disorder; SUD = Substance use Disorder.

Table 2 Number of Self-reported Alcohol and Substance Use Days Per Week [95% Confidence Intervals] in the Week Prior to the Study and During the Ecological Momentary Assessment Period.

	Alcohol Use	Substance Use
Week Prior TLFB (*N* = 61)	2.40 [1.85, 2.94]	4.64 [3.95, 5.34]
Week 1		
TLFB (*N* = 45)	2.15 [1.54, 2.76]	4.66 [3.88, 5.44]
EMA (*N* = 59)	2.28 [1.72, 2.85]	5.23 [4.74, 5.73]
r	.70 [.50, .82]	.60 [.37, .77]
Week 2		
TLFB (*N* = 42)	2.25 [1.54, 2.85]	4.17 [3.33, 5.00]
EMA (*N* = 55)	1.69 [1.23, 2.14]	4.74 [4.12, 5.37]
r	.79 [.64, .88]	.73 [.54, .84]

Note. TLFB = Timeline Follow Back; EMA = Ecological Momentary Assessment. *r* = the correlation between TLFB and EMA.

Table 3 Correlations [95% Confidence Interval] Among Indices of Self-control.

	1.	2.	3.	4.	5.	6.	7.
Monitoring							
1. Task Monitoring - BRIEF	__						
2. ERN	.22 [-.05, .45]	__					
3. FRN	.23 [-.02. 46]	.16 [-.10, .40]	__				
Adjusting							
4. Shifting- BRIEF	.46 [.23, .64]**	.21 [-.05, .45]	.02 [-.23, .28]	__			
5. PES	-.26 [-.48, -.01]	-.12 [-.36, .14]	-.07 [-.32, .18]	-.36* [-.56, -.11]	__		
Persisting							
6. Inhibit - BRIEF	.59 [.39, .73]**	.30 [.05, .52]*	-.02 [-.28, .23]	.48 [.26, .65]**	-.28 [-.49, -.03]*	__	
7. MT	-.02 [-.27, .22]	-.05 [-.30, .21]	-.01 [-.26, .25]	-.01 [-.26, .24]	.16 [-.09, .40]	-.14 [-.38, .11]	__

Table 3 Cont.

8. BH	.03	.09	-.01	-.09	.09	.09	.09
	[-.22, .28]	[-.18, .34]	[-.27, .24]	[-.33, .16]	[-.17, .34]	[-.16, .33]	[-.16, .49]

Note. $^{**}p$ >. 001, * p < .05. BRIEF = Behavior Rating Inventory of Executive Function; ERN = Error-related Negativity, FRN = Feedback Related Negativity, PES = Post-Error Slowing, MT =Mirror Tracing, BH = Breath Holding.

FIGURES

Figure 1

Probability of Substance Use at the Current Assessment as a Function of Negative Affect at the Previous Assessment and Self-reported Shifting (top panel) and Post-error Slowing (bottom panel)

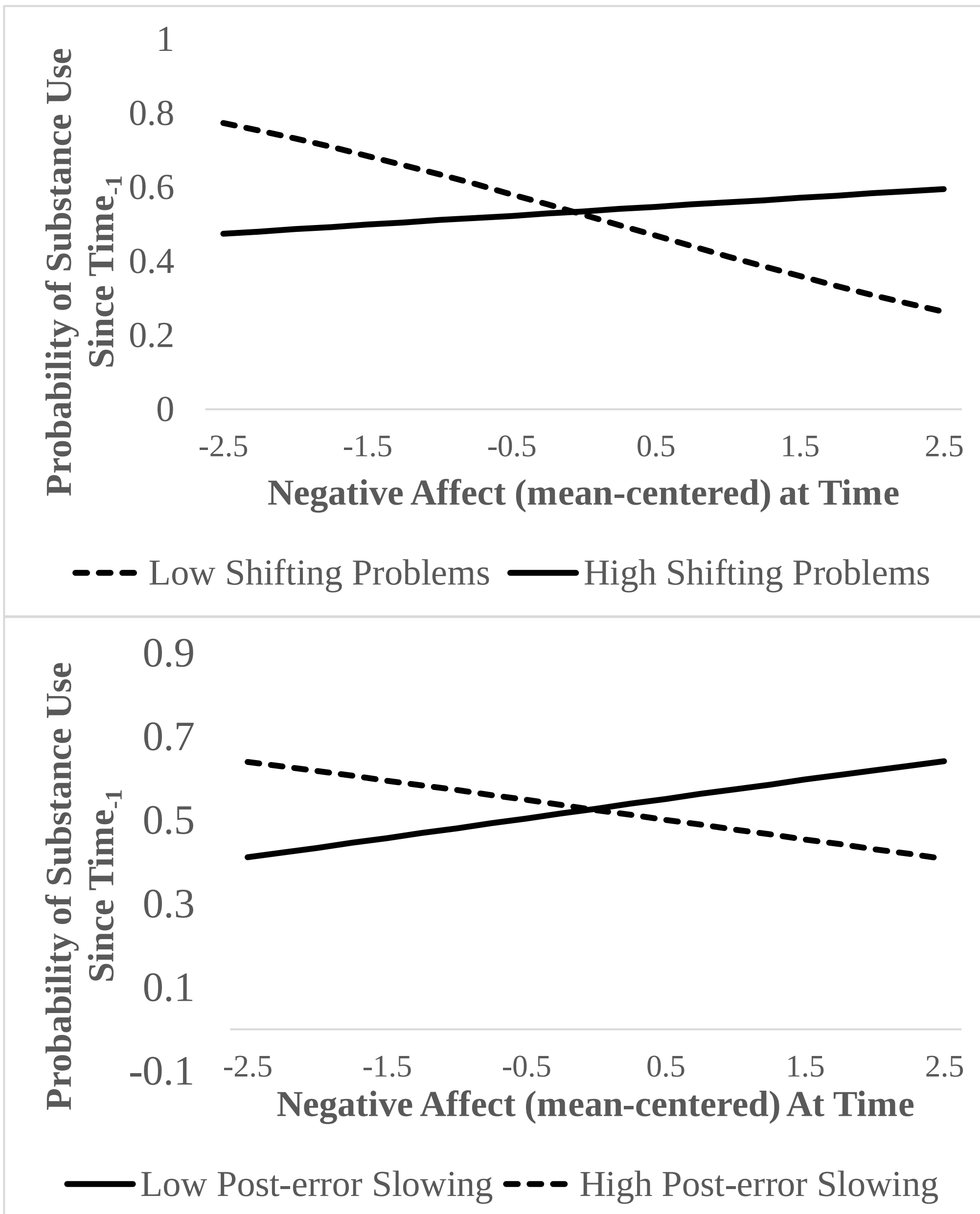
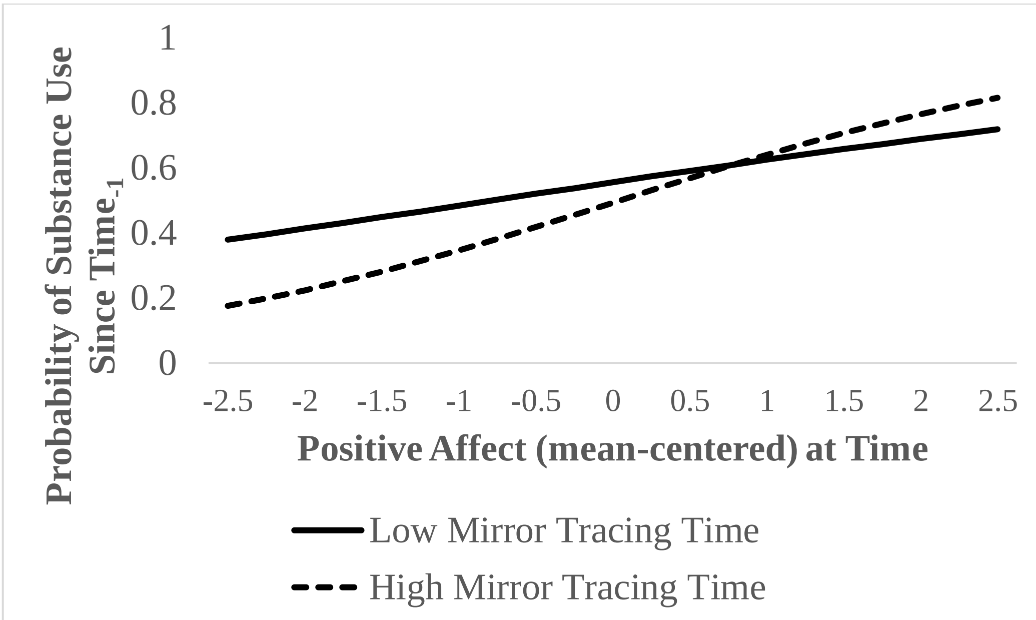


Figure 2

Probability of Substance Use at the Current Assessment as a Function of Positive Affect at the Previous Assessment and Mirror-tracing time.



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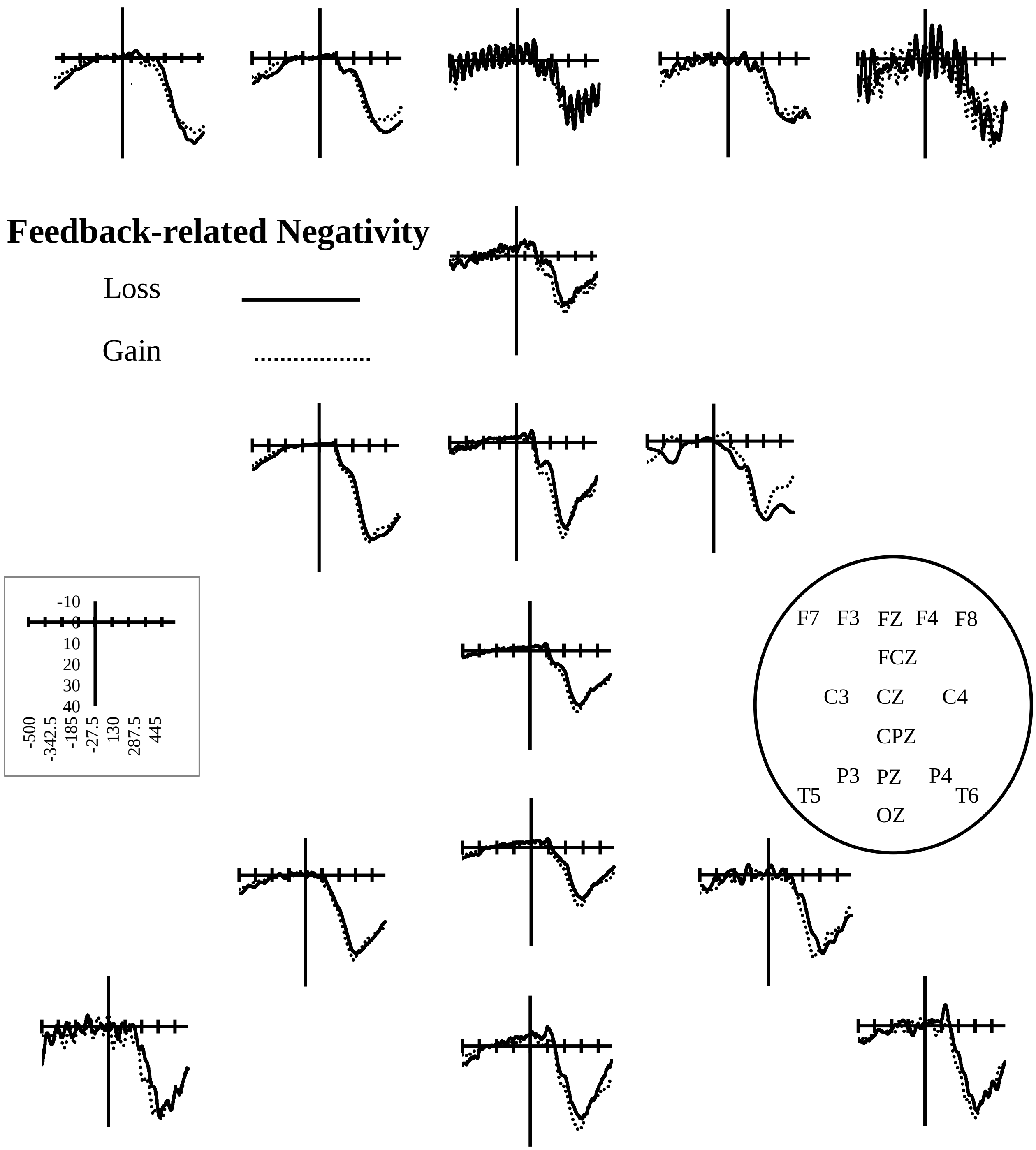
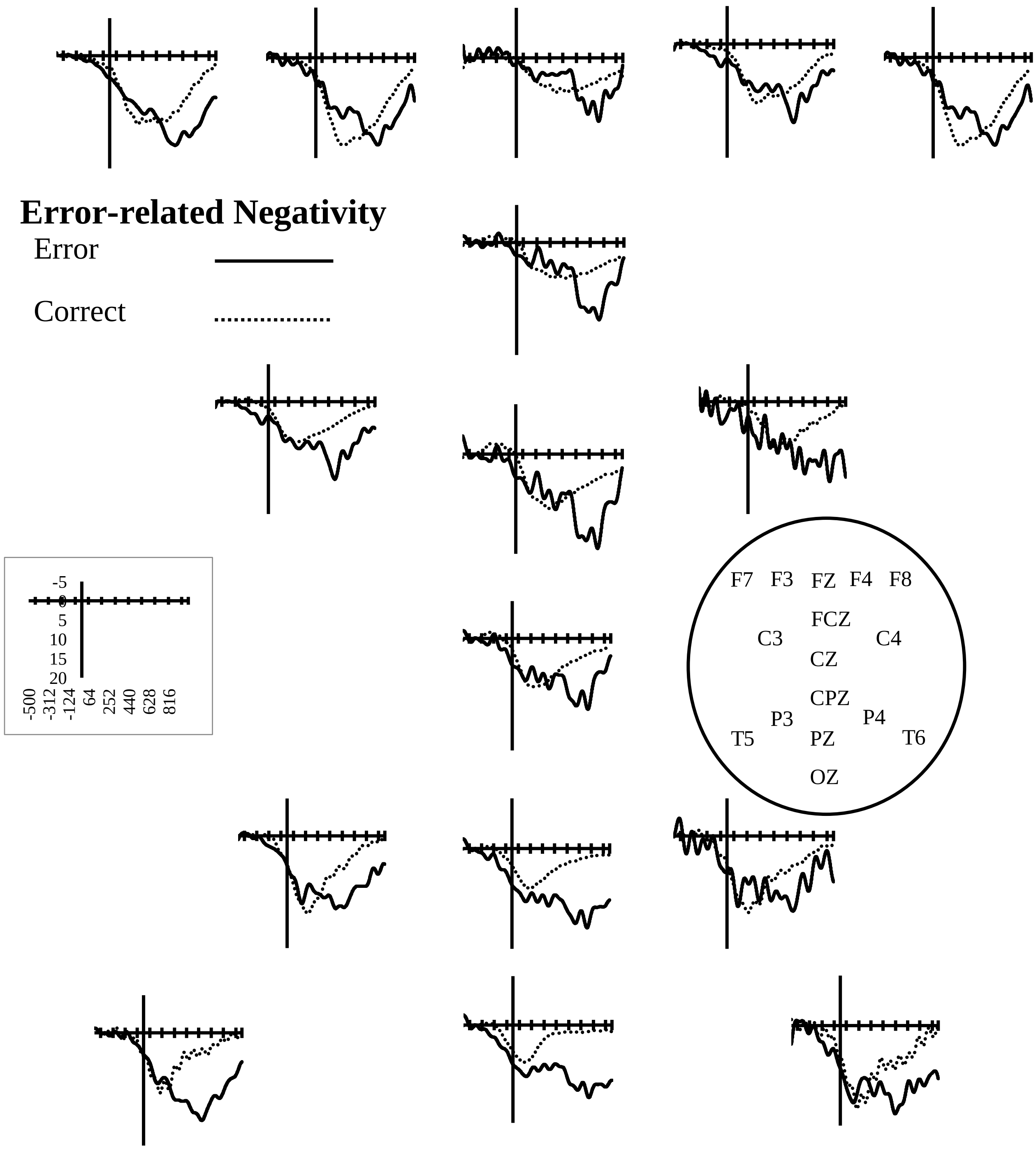
APPENDIX A – Waveform Morphology




Error-related Negativity
Error
Correct
-5
0
5
10
15
20
-500
-312
-124
64
252
440
628
816
F7
F3
FZ
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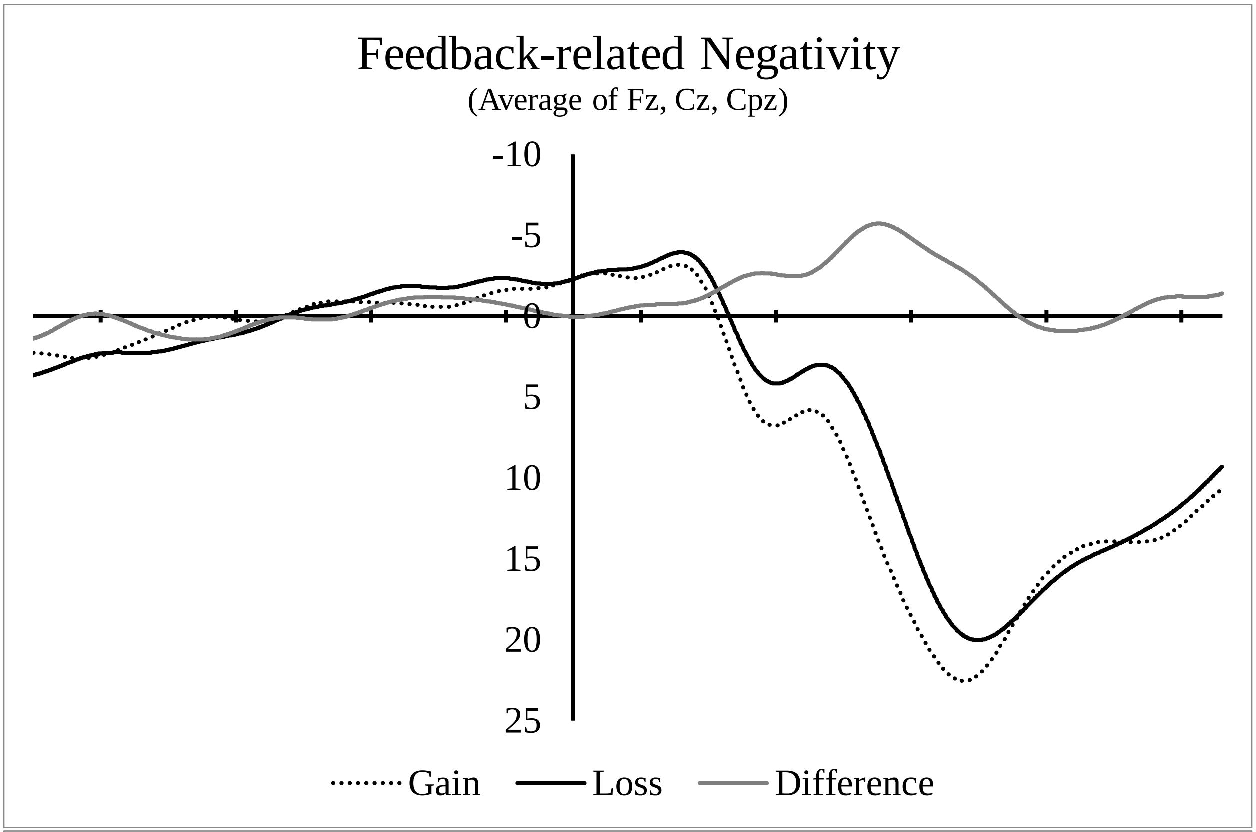
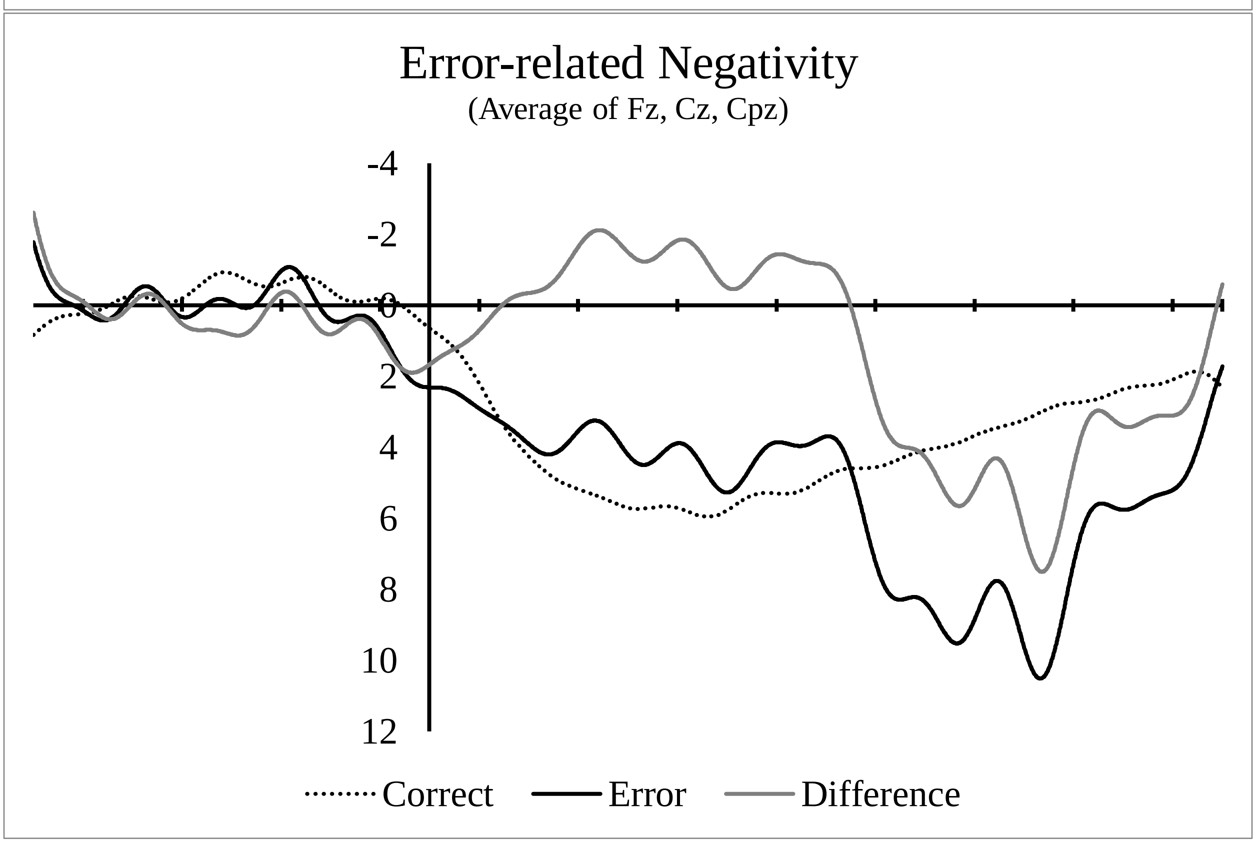
T5
PZ
T6
OZ


Feedback-related Negativity
(Average of Fz, Cz, Cpz)
-10
-5
0
5
10
15
20
25
Gain
Loss
Difference


Error-related Negativity
(Average of Fz, Cz, Cpz)
-4
-2
0
2
4
6
8
10
12
Correct
Error
Difference