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Physiological response to reward and extinction predicts alcohol, marijuana, and cigarette use two years later

Karen J. Derefinko[a,*], Tory A. Eisenlohr-Moul[b], Jessica R. Peters[c,d], Walter Roberts[c], Erin C. Walsh[e], Richard Milich[c], Donald R. Lynam[f]

[a] Department of Preventive Medicine, Center for Population Sciences, University of Tennessee Health Science Center, 66 North Pauline Street, Suite 462, Memphis, TN 38163-2181, United States
[b] Department of Psychiatry, University of North Carolina at Chapel Hill, 101 Manning Drive, Chapel Hill, NC 27514, United States
[c] Department of Psychology, University of Kentucky, 115 Kastle Hall, Lexington, KY 40506-0044, United States
[d] Department of Psychiatry and Human Behavior, Brown University, Providence, RI 02912, United States
[e] Department of Physical Medicine and Rehabilitation, University of North Carolina at Chapel Hill, CB# 7200, Chapel Hill, NC 27599-7200, United States
[f] Department of Psychological Sciences, Purdue University, 703 Third Street, West Lafayette, IN 47907-2081, United States

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ABSTRACT

Background: Physiological responses to reward and extinction are believed to represent the behavioral activation system (BAS) and behavioral inhibition system (BIS) constructs of Reinforcement Sensitivity Theory and underlie externalizing behaviors, including substance use. However, little research has examined these relations directly.
Methods: We assessed individuals' cardiac pre-ejection periods (PEP) and electrodermal responses (EDR) during reward and extinction trials through the "number elimination game" paradigm. Responses represented BAS and BIS, respectively. We then examined whether these responses provided incremental utility in the prediction of future alcohol, marijuana, and cigarette use.
Results: Zero-inflated Poisson (ZIP) regression models were used to examine the predictive utility of physiological BAS and BIS responses above and beyond previous substance use. Physiological responses accounted for incremental variance over previous use. Low BAS responses during reward predicted frequency of alcohol use at year 3. Low BAS responses during reward and extinction and high BIS responses during extinction predicted frequency of marijuana use at year 3. For cigarette use, low BAS response during extinction predicted use at year 3.
Conclusions: These findings suggest that the constructs of Reinforcement Sensitivity Theory, as assessed through physiology, contribute to the longitudinal maintenance of substance use.

1. Introduction

Innate motivational systems that govern approach and avoidance behaviors have long been recognized (Gray, 1970). The revised Reinforcement Sensitivity Theory (RST; Gray and McNaughton, 2000) indicates that three interdependent neurobiological systems influence an individual's responses to reinforcement. The behavioral activation system (BAS) guides approach behavior to conditioned and unconditioned reward. In contrast, the fight-flight-freezing system (FFFS) responds to cues for threat and promotes the avoidance of unconditioned aversive stimuli through withdrawal and freezing behavior (Gray and McNaughton, 2000). The behavioral inhibition system (BIS) serves to detect competing influences from environmental stimuli and resolve conflict by inhibiting ongoing action (McNaughton and Gray, 2002). Despite interdependence in action, these systems are differentially mediated; the BAS is believed to be mediated by dopaminergic pathways originating in the ventral tegmental area (Matthews and Gilliland, 1999), and the BIS is believed to be mediated by the amygdala and septo-hippocampal systems (McNaughton and Corr, 2004).

Self-report measures of BAS and BIS contribute to meaningful outcomes, such as various forms of psychopathology (Bijttebier et al., 2009; Mellick et al., 2014). Some have argued that abnormally high BAS activation or low BIS activation could contribute to externalizing behavior (Newman and Wallace, 1993; Quay, 1997). Given the importance of motivation for reward in the development

* Corresponding author.
E-mail address: kderefin@uthsc.edu (K.J. Derefinko).

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of problematic substance use and the shared neural substrates between substance-based reward learning and the BAS (Dawe et al., 2004; Hyman et al., 2006), it stands to reason that individuals with highly active BAS may be at high risk for substance-related problems. Consistent with this notion, there is a large literature showing that people who report high self-reported reinforcement sensitivity (i.e., heightened BAS responding) are more likely to meet criteria for substance use disorder (Hundt et al., 2008; Johnson et al., 2003). Although self-reported BIS has demonstrated relations with outcomes associated with anxiety and other internalizing conditions (Kasch et al., 2002; Mellick et al., 2014), low BIS has demonstrated less consistent relations to substance use (Franken and Muris, 2006; Hundt et al., 2008).

1.1. Measuring RST Constructs via Physiological Responses

There exists a tenuous framework linking autonomic nervous system activity with RST constructs (Beauchaine, 2001; Fowles, 1980, 1988; Tomaka and Palacios-Esquivel, 1997). In a recent review of this topic, Beauchaine (2001) asserts that cardiac pre-ejection period (PEP) and electrodermal responding (EDR) represent BAS and BIS, respectively. Shortened PEP is conceptualized as a relatively "pure" measure of sympathetic nervous system excitation that reflects beta-adrenergic influence on the heart. According to Beauchaine (2001), shortened PEP is associated with approach behavior and serves as an index of BAS activity when assessed during the delivery of reward. In contrast, increased EDR reflects cholinergic (vs. adrenergic) pathways to the skin and is unrelated to PEP. EDR is implicated in the affective experience of anxiety (Biederman et al., 1993; Scarpa et al., 1997), a characteristic associated with BIS (Fowles, 1980, 1988). When assessed during exposure to motivational conflict (changes in reward conditions), higher EDR is believed to measure BIS activation (see Beauchaine, 2001).

Despite being a novel understanding of BIS/BAS, there are emerging studies examining the utility of the physiological assessment of RST constructs. Tomaka and Palacios-Esquivel (1997) measured PEP and EDR in groups of individuals participating in a reward/punishment task. Results indicated that, as hypothesized, BAS (PEP) change scores increased and stabilized during the reward condition, but decreased during the punishment condition. While BIS (EDR) change scores were hypothesized to increase in the punishment condition, signaling the motivation to inhibit responses, no significant trend was identified. Beauchaine et al. (2001) also explored physiological BIS/BAS responding during a task of reward and extinction. Although it was hypothesized that BAS (PEP) response would increase during reward (as assessed through the shortening of PEP during reward trials), this response was markedly *low* for children with externalizing disorders. BIS (EDR) responses during extinction were not found to differentiate between children with externalizing disorders and comparison children.

To our knowledge, only one study has explored the physiological assessment of RST constructs and substance use. This is important, given that the physiological assessment of BIS/BAS may provide an important link between a useful theoretical approach and biological disorder. Incorporating prior work, Brenner and Beauchaine (2011) revised predictions to suggest that BAS responding during reward should be lowered in children and adolescents with externalizing problems including substance use. Findings indicated that low PEP response during reward trials was indeed identified as a predictor in multilevel modeling analyses of alcohol use initiation. Responding during extinction trials was not explored.

This omission of responses during extinction in Brenner and Beauchaine (2011) could be quite important. Although results from prior work have evidenced links between these RST systems and externalizing behaviors, as noted by Carver (2006), this work may oversimplify the role of the BIS/BAS in reinforcement learning. Carver has argued that responses during frustrative non-reward may be more heavily influenced by the BAS than by the BIS. This hypothesis is based on a series of studies showing that under conditions of frustrative non-reward (i.e., participants were led to believe they could earn a reward but then failed to do so), negative affective responding (i.e., frustration, sadness) was correlated with the strength of the BAS *but not the BIS* (Carver, 2004). Therefore, BAS response under conditions of both reward and the withdrawal of reward may be important in understanding how people cope with non-reward when reward is expected.

1.2. Current study

Despite known relations between self-reported RST constructs and substance use, the physiological representation of BAS and BIS can provide incremental utility in understanding how this theory lends to our understanding of biological disorder. The current study examines the utility of physiological responses during reward and frustrative non-reward (hereafter described as extinction) stimuli in the prediction of later substance use. Substance use and physiological data were collected from 230 college freshmen at year 1, and substance use data was collected again at follow-up (year 3). Physiological measures of BIS/BAS collected during a reward and extinction task were used as predictors of future substance use at year 3, controlling for substance use at year 1. With only one existing study contributing to this literature (Brenner and Beauchaine, 2011), we sought to explore relations between physiological assessment of RST constructs and later substance use.

Although Beauchaine and colleagues' work with children and young adolescents has shown associations between low BAS (lengthened PEP) responding during reward and childhood externalizing disorders (2001), we did not believe that this finding will replicate in an older, non-clinical sample given other previous work (Tomaka and Palacios-Esquivel, 1997). We hypothesized that shortened PEP responses during reward trials would indicate a stronger dopaminergic response to reward and would therefore be significant predictors of future alcohol, marijuana, and cigarette use. Due to emerging work targeting the role of BAS in frustrative non-reward responding (Carver, 2004, 2006), we hypothesized that shortened PEP response during *extinction* would be an equally significant predictor of later substance use outcomes. Although EDR fluctuations during extinction are believed to represent BIS functioning (Beauchaine, 2001), the lack of evidence associating BIS with substance use outcomes (Franken and Muris, 2006; Hundt et al., 2008) led us to hypothesize that EDR responses during extinction trials not be a predictor of later substance use.

2. Method

2.1. Participants

Participants ($N = 230$) were assessed yearly starting freshman year of college. The average age of participants at assessment was 18.49 years (SD = .72), and most were under 21 years of age (99%). Participants were recruited from introductory psychology courses and received course credit and monetary incentives for participation. Approximately 79% of participants identified as Caucasian, 13% African–American, and 8% as other.

"High risk" participants were over-recruited to ensure sufficient variability in substance use, and made up 26% of the sample. Students in introductory psychology courses were administered a screening questionnaire during a mass testing during the first two weeks of the semester. The screening measure assessed conduct problem behaviors that occurred prior to age 18 (e.g., stealing,